DOCUMENT RESUME

ED 171 535 SE 027 602

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TITLE Solar Concepts: Teacher Notes.
INSTITUTION Maine Audubon Society, Falmouth.
SPONS AGENCY Maine State Dept. of Educational and Cultural Services, Augusta. Bureau of Vocational Education.
PUB DATE 79
NOTE 141p.; For related document, see SE 027 601; Not available in hard copy due to copyright restrictions

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS *Energy; Energy Conservation; Environmental Education; *Heating; Nonformal Education; Physics; Postsecondary Education; *Science Education; *Secondary Education; *Solar Radiation; Technological Advancement; *Thermal Environment

ABSTRACT

This volume of teacher notes describes teaching methods to support the material presented in the background text and to elaborate on basic solar concepts. Included are objectives and quizzes, teacher notes and bibliographies, and selected student projects. (Author/RE)

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solar concepts

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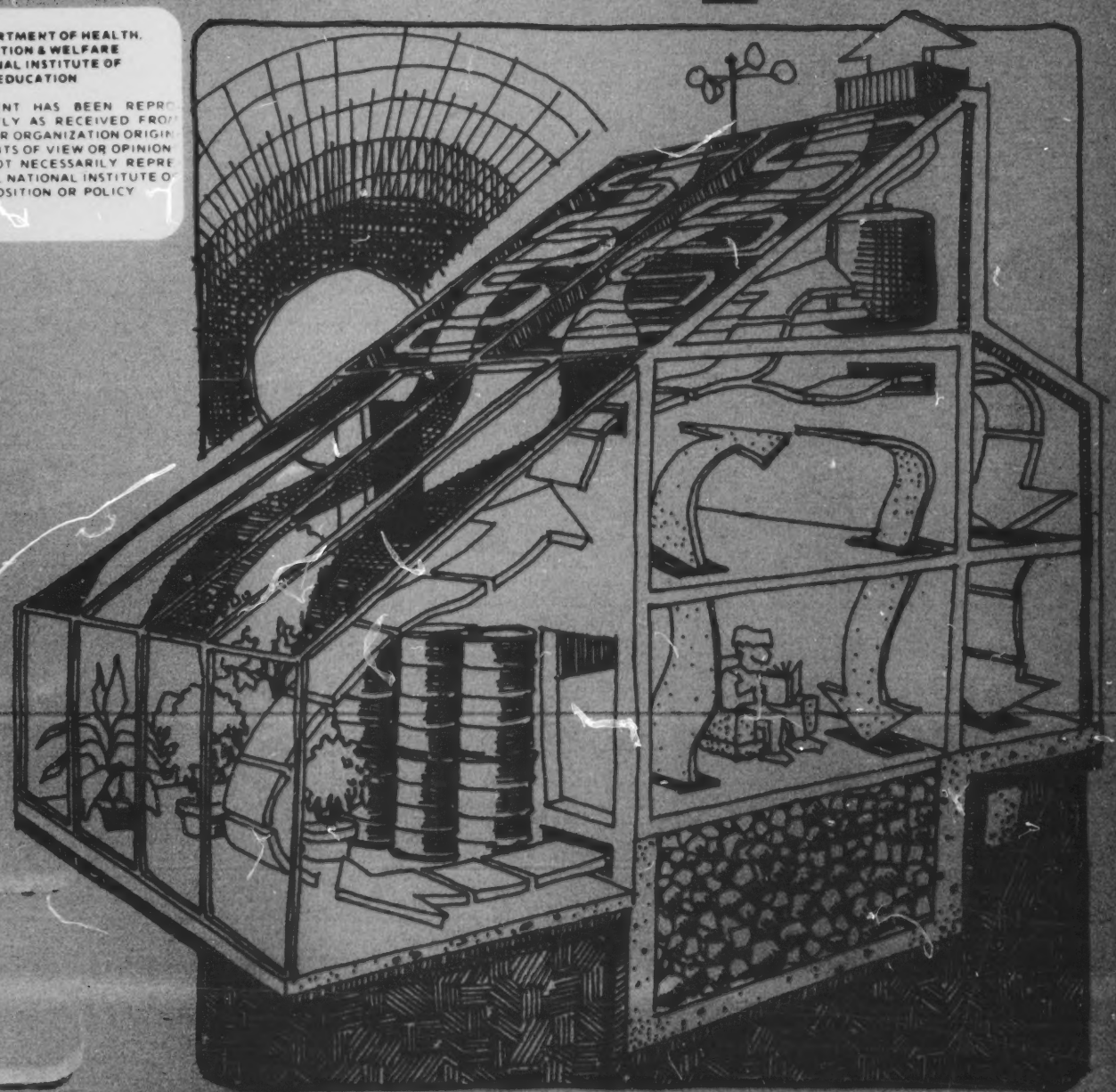

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SE 027 602

TABLE OF CONTENTS

Teacher Notes and Annotated Bibliography	Chapter 1	Page 1
	Chapter 2	7
	Chapter 3	14
	Chapter 4	20
	Chapter 5	28
	Chapter 6	33
	Chapter 7	38
	Chapter 8	42
	Chapter 9	47
	Chapter 10	51
	Chapter 11	57
	Chapter 12	62
Student Learning Objectives		69
Quizzes		74
Student Projects	Altimeter	98
	Sun Charts	102
	Parabolic Concentrator	110
	Window Collector	117
	Solar Pod	123
	Thermal Shutters	130

Note: A 180-slide set (15 slides for each of 12 chapters) with script is available. Please contact the Bureau of Vocational Education in Augusta, Maine to locate the set nearest you.

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INTRODUCTION: TEACHER NOTES

Solar energy is a newcomer to the ranks of vocational education. It is not, however, a complete stranger. Many of the technical skills needed for proper solar design and systems installation are currently part of the vocational curriculum. In solar energy the trades can work together.

Solar energy is an eclectic field; it picks and chooses from a wide variety of academic fields: astronomy, math, physics, mechanics, architecture, and even human psychology. Teaching solar energy requires a holistic view of the world. Vocational arts, the natural environment, and all modern sciences are proper areas of study.

This curriculum attempts to provide the teacher with a full array of materials. This array, however, represents but a bare bones set of tools. There is no substitute for imagination, foresight, vivaciousness and a willingness to experiment. These traits must spring forth from the teacher, that primary person responsible for constructing a vibrant yet fundamentally sound program.

The teacher notes are divided into three sections. They proceed chapter by chapter, keyed to Solar Concepts.

The first section presents a collection of teaching methodologies which can be used to illustrate key solar concepts. Unlike the Student Projects, these suggestions are general strategies, not step-by-step proceedures.

It is the refinement of and additions to this collection of teaching suggestions that will comprise the heart of this solar curriculum. I welcome and encourage a sharing of effective teaching strategies.

Following each chapter is an annotated bibliography which includes the most contemporary and useful books that I have encountered. Surely, new and more informative texts will appear. A thorough reading of these resource books provides most background information a teacher will need for each specific chapter. I welcome any and all comments regarding this selection of resource materials.

The next section contains a chapter-by-chapter statement of student learning objectives. More thorough breakdowns can be made as exemplified by those objectives drawn up for the chapter on Solar Hot Water (see Teacher Notes for Chapter 12). In addition, these objectives are accompanied by a set of six quizzes covering the following areas: pre-curriculum and final exam, and quizzes for Chapters 1-3, 4-6, 7-9, 10-12.

The Portland Regional Vocational Technical Center (PRVTC) experience revealed that many vocational students feel uneasy about written examinations. These quizzes, therefore, should be used more as evaluative tools than threatening devices. A well-balanced vocational solar program places equal, if not greater, emphasis on hands-on skills and attitude than on pure factual knowledge.

Because solar is an emerging field, however, technicians must know the facts in order to convince a skeptical public. Great opportunities will arise for those students who discipline themselves to learn basic solar concepts. The academic emphasis of this curriculum is intended to allow teachers to provide a comprehensive solar background for their students. Vocational teachers already understand the nuts and bolts of most solar installations. A re-organization of program is basically all that is required now.

TEACHER NOTES

CHAPTER ONE: ENERGY LINGO

1. Energy Terms. It is essential for students to understand these key energy terms. One method of teaching these concepts is to assign individual students key words to research. The definitions in the "Solar Terms" section are quite brief -- students should keep a notebook of solar terms which are introduced throughout the course of study. Continual quizzing of key terms forces students to learn the terminology.

2. Unit Conversions. A light board consisting of ten 100-Watt bulbs is an excellent tool for demonstrating the relationship between electrical energy (kiloWatt-hours) and heat (BTU and kilocalories).

Method: plug in the board with its bulbs loosely placed in their sockets. Have students keep track of the total wattage illuminated as each bulb is screwed into place. Ten 100-Watt bulbs equals 1000 Watts, or one kiloWatt. This method is especially effective on students sitting within a few feet of the demonstration. Also, starting with a darkened room makes this demonstration more dramatic.

Students will react to the intense heat and light coming from the unit. Electrical energy is being transformed to light and also being degraded to heat. If the unit were to be left illuminated for one hour, then one kiloWatt-hour of electricity (cost: about 4¢) would be consumed. We purchase kiloWatt-hours (kWh) of electricity from the power company.

3. Power vs. Energy Unit Distinctions. The units of power and energy are often confused. It is convenient to make a contrasting list for each category. Since we know that power is merely energy used per unit time, we can construct the following table:

Energy Units	Power Units
Joule (1000 Joules in a match)	Joule/second (1 Watt)
BTU (100 BTU in a cup of hot coffee)	BTU/hour (429 BTU/ft^2·hour = the solar constant)
Calorie (200 Calories in a hershey bar)	Calories/day (an adult eats about 3000 Calories/day)
quads (U.S. used 73 quads in 1973)	quads/year (Maine uses about .6 of a quad/year)
kiloWatt-hour (4¢ worth of electricity)	kiloWatt-hour/month (6000 kWh/mo = average Maine household consumption)

It is this last energy term (kiloWatt-hour) that gives students the greatest problems. Why, they ask, is kWh an energy term if it has a mention of time in it? Answer: a kiloWatt-hour is power through, or times, a unit of time, one hour. Mathematically, we are being quite consistent.

1 kiloWatt-hour =

1000 Watts x one hour =

1000 $\frac{\text{Joules}}{\text{sec}}$ x one hour =

1000 $\frac{\text{Joules}}{\text{sec}}$ x 3600 seconds =

3,600,000 Joules =

3.6×10^6 Joules: energy term

4. Solar Math.

A review of the law of exponents is helpful. Many of the energy units (for example, one quad = 10^{15}BTU) require familiarity with exponential notation.

The table quantifying energy in BTU times powers of ten can be used to test the students' understanding of exponential notation. Example: from the table we see there are 10^{19}BTU of solar energy striking the surface of the U.S. in one year. And in one year the U.S. consumes about 10^{17}BTU. How much more available solar energy is there than the amount of energy we use in one year?

$$\frac{10^{19}\text{BTU}}{10^{17}\text{BTU}} = (10^{19} - 10^{17}) = 10^{2} \text{ or } 100 \text{ times}$$

There exists some confusion over the terms "quads" and "Q's" of energy. The common term used in energy calculations is quad (quadrillion BTU). The quad equals 10^{15}BTU. A quintillion BTU, or a Q, equals 10^{18}BTU. In other words, a milli-quintillion equals one quadrillion. Mathematically, the relationship is:

one Q = 10^{18}BTU and m = 10^{-3} (like a mm or millimeter)

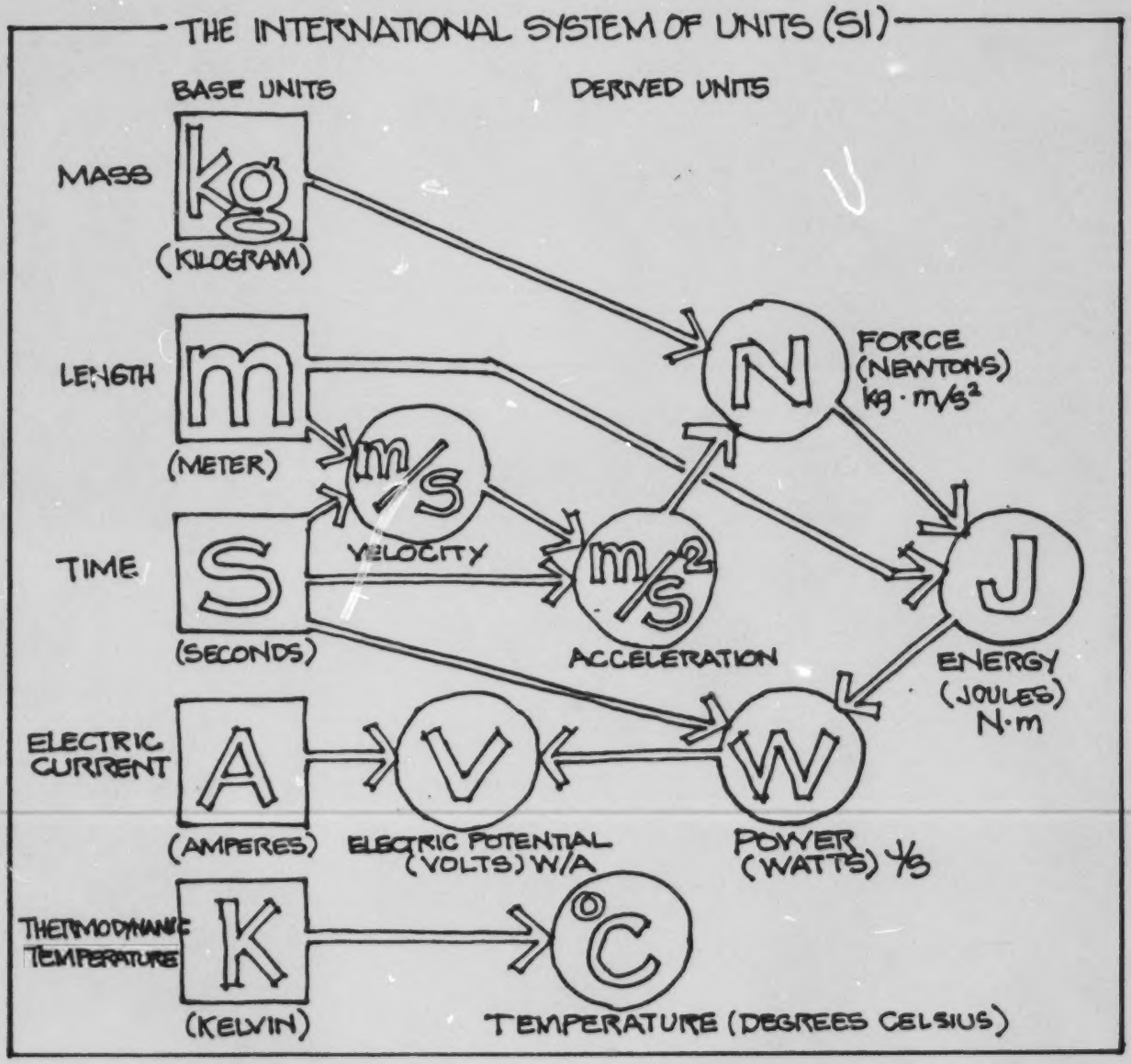
10^{-3}m

therefore mQ = $10^{-3} \cdot 10^{18}$BTU

mQ = 10^{15}BTU (a quad)

What is important to remember is that a quad is not capitalized. It is not the capital Q (Q) that is used in physics books.

The metric system is infinitely more simple to use than our cumbersome system of English units. The chart shows the relationships between the various metric units.



BIBLIOGRAPHY - CHAPTER ONE

Anderson, Bruce, with Michael Riordan, The Solar Home Book, Harrisville, New Hampshire, Cheshire Books, 1976, $7.50 paperbound.

This book provides a comprehensive introduction to the entire field. The book contains many useful example problems which involve calculations of the type done in this chapter. The book also contains a fairly complete glossary. Nearly all terms are defined and discussed in the text.

Romer, Robert, Energy, An Introduction to Physics, San Francisco, W. H. Freeman, 1976, $11.95 hard cover.

Hands-down, this book wins as the clearest, most complete introductory text. If only one book on energy can be read, choose this one. The book is written for advanced high school physics audiences. The tables are extremely useful, as are the homework problems at the end of each chapter. A Teachers' Manual is also available from the publishers. Subjects include thermodynamics, electrical, nuclear and solar energies, consumption and supply patterns. This book is a must for any serious teacher of solar energy.

TEACHER NOTES

CHAPTER TWO: RENEWABLE ENERGY SOURCES

1. Alternate Energy Technologies and Jobs. It is difficult to set a background in which students can understand the reasons for switching to renewable energy sources. Promises of future potential jobs are often not enough of a carrot to get students motivated to learn key solar concepts. Three strategies help to motivate students. They are:

1) Introduce products and units which the students can make and which have actual market potential, e.g. the projects described in the Student Projects section. Students can build an attached solar greenhouse, provided the homeowner pays for the materials. Another marketable solar product is an attractive, tiled, 2"x4" framed woodstove hearth on which students can practice wood joints.

2) Invite alternate energy business people to speak to the students. The fact that today there exist numerous examples of small businesses making a go of alternate energy technologies is solid evidence for skeptical students.

3) Visit actual construction sites of new solar houses or retrofits. Students need to see that these energy efficient houses are actually being built. Seeing is believing. The state Office of Energy Resources in Augusta, and the Maine Audubon Society in Falmouth can provide names and addresses of such sites.

2. Understanding the Energy Crisis. Because conflicting information about the "energy crisis" abounds, students should be asked to clip out all relevant articles in magazines, newspapers, etc. A good way to begin is to ask the basic question: Is there an energy crisis? How do you know? This question is very difficult to answer. Debates should be staged to re-assess information as it filters in.

Consult the state Office of Energy Resources, as well as interested local groups like the Portland Energy Reduction Team (PERT) and the Maine Audubon Society to keep this key question in focus. Several other techniques work well:

1) Students can tape interviews with various energy professionals: house contractors, oil dealers, woodstove dealers, utilities workers, and also the general public.

2) Teachers should watch for local energy conferences like Maine Audubon's Clearinghouse Fair, television and radio broadcasts, and special newspaper editions.

One central concept important to remember is that no one player in this complex energy chess game is to blame. We all, as an energy-intensive society, are responsible for the effects of our increased energy use.

One exciting educational strategy is to have each student calculate his or her own personal energy consumption. Understanding that we are all culprits is an essential first step in solving the problem.

Another strategy is for students to perform a detailed energy audit on their own homes. In the Bank or Up the Chimney is an excellent book to use for this purpose. This publication is available from the state Office of Energy Resources for 55¢.

Students can also be required to keep a weekly energy use chart. They should write down everything they do over a one-week period that requires a direct (putting gasoline in their cars) or indirect (eating canned Hawaiian pineapple) energy investment. In stark contrast to their present lifestyles, assume that students must go out into the wilderness to live for one week. What energy resources will they bring with them, and which ones can they get along without?

3. Exponential Growth. For two reasons the study of exponential growth is important. It forces students to review powers of 10 notation, and it forces students to recognize the speed with which a problem can become a serious crisis. Several methods for teaching exponential growth follow.

1) Pose the question: "Would you rather have $1,000 per day for every day in November, or 1¢ the first day, 2¢ the second, 4¢ the third, etc.?" Which method accumulates more cash? On which day will the exponential accumulation exceed the linear?

2) Take a piece of paper and fold it in half. How many rectangles are formed? Fold the previously folded paper again in half. How many rectangles are now formed? Fill in the following table:

# of folds	# of rectangles
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128

It is impossible to fold any piece of paper more than 7 times. Only the Lilliputians know why.

Two key concepts go hand in hand with exponential growth. The first is that the last increment is greater than the total of all increments up to that point. In other words, if the electrical consumption doubles every 10 years, then in the time span 1978-1988, more electricity will be used in that decade than was used during all previous decades, e.g.:

$$16 > 8 + 4 + 2 + 1$$

$$16 > 15$$

The second key concept is that doubling times can be approximately determined by the formula $\frac{70 \text{ years}}{\% \text{ annual increase}}$

Students can see the effect of various percentage growth patterns. The teacher can pose the question: what will the doubling time be if our increase of petroleum use is 2% per year, or 4%, or 8%? (Remember, a doubling time means twice the pollution.)

BIBLIOGRAPHY - CHAPTER TWO

Bender, Tom, Environmental Design Primer, New York, Schocken Books, 1973, $5.95 paperbound.

This book provides that holistic overview that solar educators need. The author compiles an inspiring collection of essays, poems and "meditations on ecological consciousness." This book draws from the wisdom of many cultures. Its goal is to help us understand and use technology to humanize life.

Commoner, Barry, The Poverty of Power: Energy and the Economic Crisis, New York, Alfred A. Knopf, 1976, $2.95 paperbound.

The author points out the interrelationships among energy technologies, economics and environmental degradation. Commoner describes some unsettling long term effects of our over-dependence on non-renewable energy sources. His discussion of thermodynamic, source-task matching is particularly good.

Hayes, Denis, Rays of Hope: The Transition to a Post-Petroleum World, New York, W.W. Norton and Company, 1977, $3.95 paperbound.

The author sets solar energy into its historical perspective. Filled with a wealth of information, the book argues convincingly why alternative energy sources must be developed. In addition the book

discusses the social changes that will accompany the choice of any particular energy technology.

Lovins, Amory, Soft Energy Paths: Towards a Durable Peace, San Francisco, Friends of the Earth International, 1977, $6.95 paperbound.

This book spells out in no uncertain terms the economic implications of the industrialized nations' overdependence on non-renewable energy sources. The book contains mountains of data and technical information directed to the serious student of energy policy. The book is considered a classic.

TEACHER NOTES

CHAPTER THREE: HISTORY OF SOLAR

1. Develop a Sense of Energy History. It is important for students to recognize that liquid fossil fuels were not always the primary fuels for our society. Have students interview their grandparents to collect impressions of what life was like before the fuel oil truck. Try to get stories about heating with coal or wood. What were the environmental costs? Was it a lot of work? Ask the fundamental question: why did the switch occur?

2. Oil Dealers. Many oil dealers who have been in business for some time have been involved in selling other fuel products. Schedule interviews with them to learn about their companies' pasts. When did their shift to petroleum occur? What do they see as the future of their oil supply? What do they see as a future for energy conservation and solar?

3. Sun Worship in Other Countries. From the beginnings of civilization, human societies have worshipped the sun as the giver of life. Students should research non-contemporary cultures (i.e. the Mayas in Central America, 1000 A.D., or the Egyptians, 2500 B.C.) to see how sun worship played an important part in the religious and social life of these

peoples. Are there any sun-worshipping cults alive today? If so, what are their rituals and customs?

4. Oil Subsidy. The emergence of the oil companies to the forefront of power in the United States is a poorly understood fact. It has been estimated that these large corporations (Exxon, Phillips Petroleum, Gulf, etc.) have been granted more than $100 billion in federal subsidies. Have students prepare a list of the 20 largest corporations in America. How many are oil companies? Write to these companies to request copies of their annual reports, as well as statements on their attitudes toward solar and energy conservation. Prepare a report on the oil depletion allowance. Following the rise of Standard Oil Company through history provides an excellent case history of how such companies have gotten where they are. Read Oil Power by Carl Solberg, New American Library, New York ($1.95 paperbound). Finally, catalog the number of solar businesses that are owned by these large corporations. Have students predict the relationship between solar energy development and the large oil companies for the next 5, 10, and 20 years.

5. Firewood Use. Although people think of firewood as a primitive energy source, it provides as much power around the world as does nuclear energy. Get the results of a study done by the Maine Audubon Society on the burning of

wood in Maine homes. Develop a chart of the number of students whose families heat with wood. When did the switch to wood occur? Have the students' families always heated with wood? What lifestyle changes are required for heating with wood? See if the results of the Audubon report (46% of all Maine households use some wood heat) agree with class statistics. Where does the wood come from? Can it be considered an inexhaustible fuel resource?

6. Solar Installations. Catalog any and all solar installations within your school district. Plot a graph of the number of solar systems built during the past five years. The Maine Solar Energy Association, Monmouth, Maine 04259 can help provide names and addresses of solar installations in your area. The Office of Energy Resources, 55 Capitol Street, Augusta, Maine 04333 also has compiled a list of solar installations within the state. Use this information to chart the rise in number of solar applications for your area. What predictions can you make for the future?

7. Newspaper and Magazine Clippings. Students should keep an up-to-date file of newspaper and magazine articles on solar applications, past and present. Develop a formal filing system, so that students can locate materials easily. Take 35mm slides of pictures of installations in these articles. Use these slides for student presentations to other students

in the school, community groups, and the general public. Spread the word that solar is not new and that it is growing.

BIBLIOGRAPHY - CHAPTER THREE

Anderson, Bruce, The Solar Home Book, chapter 2 "Solar Architecture".

This chapter presents most of the classic solar houses including those by Dr. George Löf and by Dr. Maria Telkes and the first four MIT experiments. Within the 35 pages in this chapter the author discusses many of the pioneer solar structures.

Clark, Wilson, Energy for Survival: The Alternative to Extinction, New York, Anchor Press, 1975, $4.95 paperbound.

This work is truly enclycopedic in nature. It sketches out in detail the histories of both solar and fossil fuel technologies. The book is extremely well written and packed full of interesting historical data.

Daniels, Farrington, Direct Use of the Sun's Energy, New York, Ballantine Books, 1974, $1.95 paperbound.

This book in itself represents a piece of solar history because throughout the 1950's and 1960's it was Daniels who produced much of the early solar documentation. Chapter 2 of this book is devoted to solar history. This is an amazing book, considering its publication date.

U.S. Department of Housing and Urban Development, Solar Dwelling Design Concepts, Washington D.C., AIA Research

Corporation, 1976, $2.30 paperbound.

In a very direct, simplified manner this book presents the same information as Anderson's. For the price, this book contains much useful, well-illustrated information. Chapter 1 is entitled "Solar Energy: An Old Idea Reborn." It is a useful eight pages, with many drawings, photos, and illustrations.

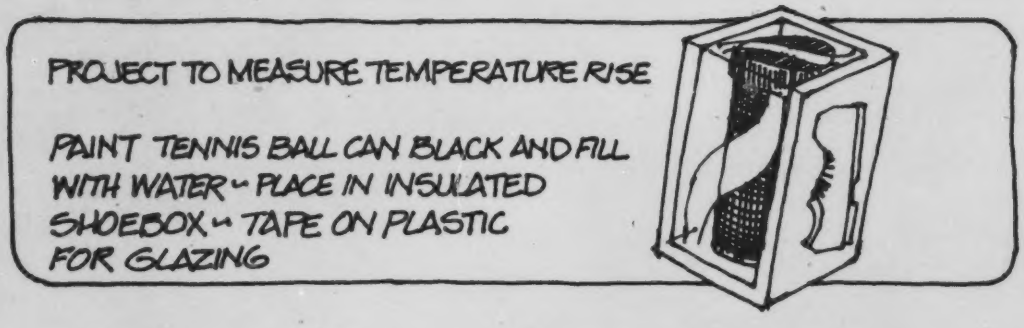
TEACHER NOTES

CHAPTER FOUR: QUANTIFYING SOLAR

1. Measuring BTU. It is important that students learn to measure or quantify solar radiation. Our national energy consumption is expressed in quadrillion (10^{15}) BTU; therefore, students must become familiar with the concept of a BTU. Start small. Measure the volume of a standard tea pot. Calculate the weight of the water. Measure the starting temperature of the water. Apply heat. Measure the temperature of the water at specific intervals of time. At each time interval, calculate the number of BTU the water has absorbed. Make sure students understand how to work with the BTU definition: number of BTU = number of pounds of water times the difference in Fahrenheit temperature (BTU = weight x ΔT). Have the students devise their own experiments to demonstrate their knowledge of BTU measurement (e.g. measuring the temperature of a soda immediately after it is removed from the refrigerator and again one hour later.)

2. Measuring Sunshine. Once students are comfortable with BTU calculations, have them design solar calorimeters. These devices are nothing more than simple tennis ball cans with lids enclosed in shoe boxes which have been insulated and covered with clear plastic wrap or polyethylene. Each student

can make his or her own.


PROJECT TO MEASURE TEMPERATURE RISE
PAINT TENNIS BALL CAN BLACK AND FILL WITH WATER ~ PLACE IN INSULATED SHOEBOX ~ TAPE ON PLASTIC FOR GLAZING

For better absorption, the cans can be painted black and the inside of the box can be lined with aluminum foil. The rear box panel should be removable or hinged so that the water container can be taken out. Students can have a competition to design the most efficient collector. Comparisons can be made among various designs. Performance is based on the rise in temperature of a specific amount of water after the unit is left in the sun for a specified period of time. The class can determine the best (i.e. most durable, efficient, or aesthetically pleasing) calorimeter design. This unit can then be used to measure daily insolation. Provisions must be made to provide similar test conditions each day (wind, exposure to the sun, etc., must not change). The easiest way to guarantee this is to perform the test through a south-facing window, thereby isolating the effects of wind and outside temperature. The major objective is to get relative measurements of available sunshine on each day over a test period.

The results of this experiment should be cross-checked with local meteorological data, which lists insolation and percentages of sunshine for various days. Students should keep a chart which tabulates the following information:

Solar weather chart

LOCATION: _____ PERSONS RECORDING DATA: _____

LATITUDE: _____

ALTITUDE: _____

MONTH/YEAR: _____

DATE	TEMPERATURE			DEGREE DAY 65° BASE	(INCHES) PRECIP.		RELATIVE HUMIDITY		AVG. WIND		SUNSHINE		PHOTOCELL OUTPUT	WHAT HAPPENED?
	Hi	AVG.	LOW		SNOW	RAIN	AM	PM	SPEED	DIRECTION	BTU/FT²	%POSSIBLE SUNSHINE		
1														
2														
3														
4														
5														
6														
7														
8														
9														
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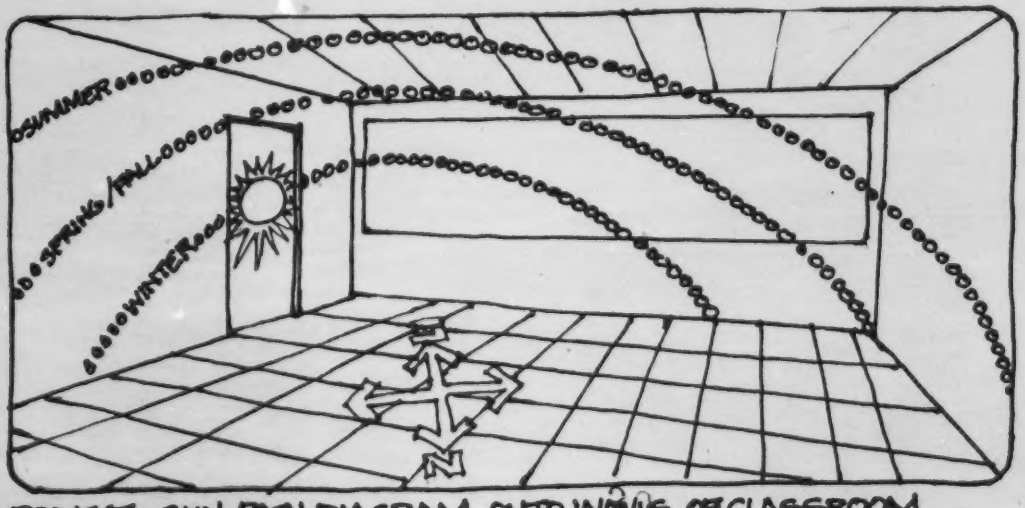
3. Photo Cell - Insolation Meter. Purchase from Edmund Scientific a photocell of known current output. Place this cell in direct sunlight and measure its performance. Compare its output to local pyrometer readings. Calibrate the photocell to allow you to measure the sun's intensity. This photoelectric data can also be entered into the solar weather chart.

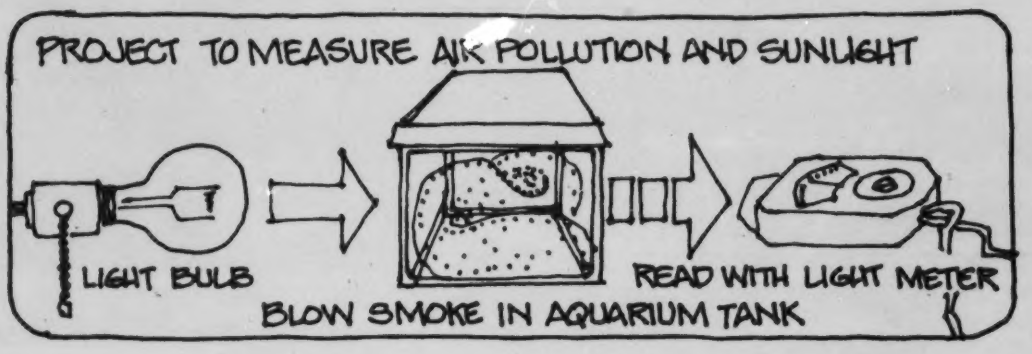
4. Earth/Sun Relationships. Use a flashlight (as a light source) and a variety of spheroids (basketball, beachball, etc.) to demonstrate the seasonal tilt of the earth. Using white athletic tape, attach outlines of North America, the equator, and other prominent globe markings. Have students demonstrate the phenomenon of earth axis rotation as it affects the intensity of the received light source.

5. Sun Path Diagrams. Inside, on a south-facing wall of the school, have students paint the path of the sun during three key times of the year: 1) summer equinox, 2) winter equinox, and 3) spring and fall equinoxes.



PROJECT SUN PATH DIAGRAM ONTO WALLS OF CLASSROOM

6. Pollution and Sunshine. Use a light meter, a light bulb and an aquarium tank with a lid on it. The purpose of this exercise is to measure the effect of air pollution on available sunshine. Begin the experiment by directing a beam of light at an aquarium tank. Record the light meter reading.



Fill the tank with cigarette smoke or some other noxious fumes. Then record the light meter reading. Consult with the Department of Environmental Protection to learn about the major air pollutants in your locality (paper mill smoke, refinery smog, bean factory clouds, etc.). Use this information to try to approximate worst case conditions for your area, i.e. those times when the percentage of possible sunshine was limited because of air pollution. The goal is to demonstrate the adverse effects of air pollution on solar potential.

BIBLIOGRAPHY - CHAPTER FOUR

Cole, John and Charles Wing, From the Ground Up, Boston, Atlantic, Little Brown, 1976, $7.95 paperbound.

This excellent book covers the basics of passive solar design. The book is particularly pertinent to Maine shelter construction since much of the information is drawn from the practical experience of house builders in this state. The presentation on solar gain is particularly useful.

Daniels, Farrington, Direct Use of the Sun's Energy, chapter 3 "Solar Radiation".

In these twenty pages the author lays out the basics of solar radiation.

Kreith, Frank and Jan Kreider, Principles of Solar Engineering, New York, McGraw-Hill, 1978, $24.50 hard bound.

This book is a high-level engineering text filled with a wealth of solar information. Chapter 2 is entitled "Fundamentals of Solar Radiation". This text contains just about everything an engineer needs to know. To the lay person the calculus is most incomprehensible. However, the writing is well done, so that the book has great value for non-mathematicians who can understand basic concepts by reading introductory and concluding chapter paragraphs.

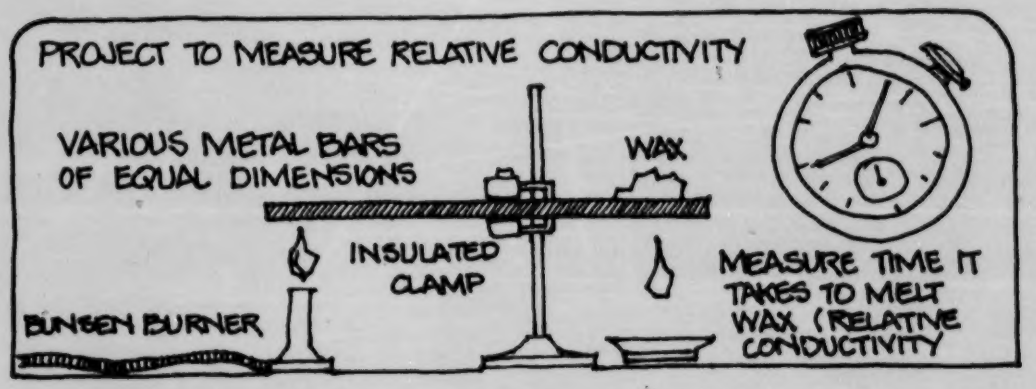
Energy Primer, Freemont, California: Fricke-Parks Press, 1974, $4.50 paperbound.

This book contains many practical suggestions for harnessing solar. Also it presents ten pages of appendices which explain solar radiation basics.

TEACHER NOTES

CHAPTER FIVE: PRINCIPLES OF HEAT TRANSFER

1. Conduction. Conductive heat transfer is easy to understand. Several experiments can help clarify that intuitive understanding. Locate similar cross-sectional strips of different non-combustible materials like glass, porcelain, iron, copper, aluminum, brass. Make sure they are all the same length: 18". On one end of each strip, place identical globules of candle wax. Make sure all wax chunks are identical.


PROJECT TO MEASURE RELATIVE CONDUCTIVITY
VARIOUS METAL BARS OF EQUAL DIMENSIONS
WAX
INSULATED CLAMP
BUNSEN BURNER
MEASURE TIME IT TAKES TO MELT WAX (RELATIVE CONDUCTIVITY

Record the length of time required for the wax to melt on the various materials tested. Graph these results. Then look up the R-values of these various materials in a reference text such as the CRC Handbook of Chemistry and Physics. How do your results compare with those calculated in the laboratory? Critique the experiment.

2. Radiant Heat Transfer. This method of heat transfer is the least understood by the general public. However, woodstoves rely on this method of heat transfer. About 70% of the heat given off by a woodstove to a room is by radiant exchange. Take an Astrolon® space blanket (available from L.L. Bean). Wrap a student up in it. Have the student describe his or her sensations. The reflection of body heat from the aluminized fabric keeps the student warm. Another way to illustrate this phenomenon is to place a piece of aluminum foil one inch away from your cheek. What do you experience? As in the space blanket case, you should feel the reflection of your own body heat. It is as if another person were one inch away from you.

Have students try the following experiment. Mount a room thermometer on a small piece of plywood scrap. Place this thermometer facing the woodstove. Record the temperature after 10 minutes. Ten minutes later, place the same thermometer behind a massive obstacle (like a wall or couch) at the same distance from the woodstove and at the same elevation from the floor. Record the results after 10 minutes. What can you conclude about the blocking of radiant heat?

3. Infiltration. One of the most difficult tasks in evaluating the thermal performance of structures is computing an accurate air exchange rate. Consult with local engineers or Heating, Ventilation, and Air-Conditioning (HVAC) contractors as to their methods of computing air exchange rates. Compare their

results to the following table:

2-3 air exchanges (AE) per hour: a breezy, uninsulated house

1 AE per hour: a standard insulated house

½ AE per hour: a tightly constructed, energy-efficient house

Reformulate a table to help your students ballpark guess air exchange rates. Have students perform infiltration analyses on their own houses and on the school. Contact the Office of Energy Resources for samples of energy audits done on schools throughout the state. If possible, secure the audit done on your own school and compare your observations with those of the auditors.

4. Energy Audits. From the Office of Energy Resources in Augusta, secure copies of their residential energy audit form. Go over all terms and the suggested procedures for filling out the forms. Also refer to the book In the Bank or Up the Chimney. Have students watch for advertisements for commercial energy audits that occur in the local newspapers. The list of commercial auditors can be obtained from OER. Contact these businesses for descriptions of the services they provide.

The A.R. Wright Company at 315 Park Avenue, Portland, Maine 04101 and the Day's Oil Company, 177 Turner Street, Auburn, Maine 04210 both offer a free energy audit service for their customers. Write to either company to request their brochure

entitled "Energy Audits by Cornerstones". Compare the costs and benefits of all audit programs.

5. Insulation Types. Gather about a dozen samples of the most common insulation materials: styrofoam, fiberglass, cellulose, ureaformaldehyde, etc. Place these substances in plastic sandwich bags, or cut out 4" square chunks of the rigid materials. Glue or staple these samples to a large board for display purposes. Include the following information: insulation name, R-value per inch, cost per inch, dollar per R-value, and special properties. For 30¢ obtain a copy of the January 13, 1978 Maine Times (41 Main Street, Topsham, Maine 04086). This issue includes an informative table "A Field Guide to Insulation". The table lists the six most common types of insulation, including information on properties, advantages, disadvantages, method of installation, and cost.

Try to obtain free samples of the insulation types from local insulation or building supply companies.

BIBLIOGRAPHY - CHAPTER FIVE

Anderson, Bruce, The Solar Home Book, chapter 3 "Fundamentals: Understanding and Calculating the Energy Flows Around a House".

This book spells out most of the basics for calculating heat load. Case studies help to explain the use of formulas.

Cole, John and Charles Wing, From the Ground Up, Boston, Atlantic, Little Brown, 1976, $7.95 paperbound.

In my estimation this book is the most thorough in presentation of heat loss calculation methodology. Anyone who reads the text carefully and works through the example problems will know enough to do most all heat transfer problems.

Leckie, Jim, Gil Masters, Harry Whitehouse, and Lily Young, Other Homes and Garbage, San Francisco, Sierra Club Books, 1975, $9.95 paperbound.

This book is remarkable in its comprehensiveness. It contains a wealth of usable formulas and data. The drawings are excellent and case studies are used to elucidate the theory. The section on solar contains discussions of thermal comfort, climatology and heat loss. A summary of the methodology for calculating heat loss is included.

TEACHER NOTES

CHAPTER SIX: PASSIVE SOLAR

1. Overhangs. Essential to most passive solar structures is proper design of a south overhang. It is necessary for students to understand sun angles so that overhangs can be designed to allow maximum sun during the winter and minimum sun in the summer. Design a series of house overhang situations to test the students' understanding of sun angles. Use the following altitude angles for the following latitudes at specific times of the year. Use metric rulers and protractors to design effective overhangs.

	North Latitude	42°	44°	46°
DAY	December 21	24	22	21
	March & September 22	48	46	44
	June 21	72	69	67

(altitude angles at solar noon)

An effective solar overhang is one which blocks all summer sun (June 21) from the south wall.

Completion of this exercise presupposes a working knowledge of sun angle charts. Students must understand how to predict the sun's location. In this specific case, finding the solution requires a working familiarity with geometry or an ability to construct a model and to use a point light source to simulate real world conditions.

A more advanced exercise is to ask students to design a south wall and overhang so that the sun strikes the lower half of the back wall of the structure. In this case the entire geometry of the house must be considered.

2. Passive Design. Obtain free of charge from the government the booklets "Passive Design Ideas of the Energy Conscious Architect", "Passive Design Ideas for the Energy Conscious Consumer", and "Passive Solar Design Ideas for the Energy Conscious Contractor". These documents are available from the National Solar Heating and Cooling Information Center, P.O. Box 1607, Rockville, Maryland 20850. Use these booklets to stimulate passive solar design thinking. From looking at these designs, students should be able to spell out a list of passive solar design principles. Draw up a chart of these key concepts. Have students design their own "dream houses" using these concepts. Have the entire class critique each student's design.

3. Public Acceptance of Passive Solar. To a large extent, the general public is skeptical of passive solar. For most

people the words "solar energy" mean flat plate collectors, pumps and heat exchangers -- the hardware of active solar. Passive solar appears too simple or technologically unadvanced for the average consumer. People are suspicious of "something for nothing."

Set up a public display at an energy or trade fair which demonstrates basic passive solar design concepts. Formulate a questionnaire to assess people's attitudes towards passive solar. Try to determine if people understand the difference between active and passive systems. Explain key energy terms. On the basis of the information gleaned from these questionnaires, re-design your public education displays to address the appropriate issues.

4. Framing Options. Obtain the Owens-Corning booklet entitled "The Energy Conserving Arkansas House" from the local Owens-Corning representative or the company's field office in Waltham, Mass. Draw up plans for a 10' x 32' wall using both 2"x6" and 2"x4" frame construction. Make detailed cost comparisons considering amount and cost of wood, and fiberglass insulation. Compare these costs to their effective R-values. Does it pay to go with 2"x6" studs? Compare these results to using a standard 2"x4" stud wall with 1" rigid insulating board (R-5.5 per inch) as an exterior insulation under the sheathing. Of the three options, which is the most cost effective (i.e. how do the costs in $/R ratios compare?) What other issues are

involved for the contractor?

5. Earth Berming. Building earth up around a house is one method of cutting down heat loss. Other people advocate setting houses deeply into the ground. A good introductory article is found in "Smithsonian" Magazine, February 1979.

Have students assemble pictures and photographs from magazines of underground houses. What are the advantages and disadvantages of underground housing? Are there any major design impediments to widespread construction of underground houses in Maine? What sorts of lifestyle changes, if any, could result from living in an underground house?

BIBLIOGRAPHY - CHAPTER SIX

Cole, John and Charles Wing, From the Ground Up, Boston, Atlantic, Little Brown, 1976, $7.95 paperbound.

This book is considered by many to be the most useful for the basics of passive solar design.

Mid-Atlantic Solar Energy Association, Proceedings of the 2nd National Passive Solar Conference, American Section of the International Solar Energy Society, 1978, $20.00 for the three-volume set paperbound.

These proceedings and the forthcoming 3rd National Conference papers collectively represent the state of the art of passive solar design and application. These books offer a wealth of current research information, an absolute must for serious solar designers. These materials are well worth the price.

Wright, David, Natural Solar Architecture: A Passive Primer, New York, Van Nostrand Reinhold Company, 1978, $7.95 paperbound.

This book accomplishes what it sets out to do; it offers a complete primer of passive solar design. The text is hand printed. The illustrations are cartoon-like. The net result is disliked by some, loved by others. I personally enjoy the author's writing style and the mode of presentation. My high school students also very much enjoyed the materials. A well done book.

TEACHER NOTES

CHAPTER SEVEN: WINDOWS AS SOLAR COLLECTORS

1. Window Placement. Pick a sample neighborhood of at least twenty houses. Do a sampling of window placement. How many of the houses have windows equally placed on all four walls? How many of the houses are lined up on an EAST-WEST axis enabling them to maximize solar gain? Do any of the houses use insulating curtains or shutter devices on cold north-facing windows?

Use a compass to determine true south. (Remember: the compass needle points roughly 17^{o} west of true north in Maine.) From a solar standpoint, what percentage of the twenty or more houses has good solar orientation (i.e. which ones are on an EAST-WEST axis and have 20%-50% of the south wall as glass?) Try to find an ideally situated house in the neighborhood. Assign students a project to design a "solar subdivision", one in which each house has significant opportunity for solar gain without shading its neighbors.

2. Glazing Materials. Contact the National Solar Heating and Cooling Information Center (1-800-523-2929). Ask for a list of solar collector glazing materials manufacturers. Compare each of these products relative to the following characteristics: cost per square foot, ultraviolet degradation, weather-

ability, clearness, ease of installation, infrared transmission. On the basis of these comparisons, rate all of the commonly available glazing options. Make up a display board which presents all of this information clearly.

3. Insulating Shades and Shutters. In order to make the most effective use of the solar gain potential of any glazed surface, that surface area should be open to the sun in the day and sealed off at night. A variety of insulating shades and shutters is now commercially available. Watch for advertisements in local papers for these products. Contact the Office of Energy Resources in Augusta or the Maine Audubon Society for up-to-date information concerning these products. Construct a display which demonstrates how each of these devices works. Detailed cost comparisons could include: cost per R-value, cost per square foot, ease of operation, guarantees, and aesthetic concerns.

4. Window Box Collectors. Popular Science and Mother Earth News, along with several other appropriate technology publications, have presented plans for window box collectors. Collect these diagrams and plans. From them, determine the best design. Construct a window box collector using as inexpensive materials as possible. Keep a detailed accounting of the materials and labor that go into the production of a window box collector. After installation of the collector, place thermometers at

both the intake and exhaust openings. Tabulate these results. Does the window box collector cause any appreciable change in room temperatures? It is essential that the window collector be properly sealed so that infiltration losses be kept at a minimum.

5. Thermopane Units. Compare the results of the window box experiment or the tennis ball can experiment (see Teacher Notes: Chapter Four) using single versus double (3/4" air space) glazing. Watch the rate of temperature drop of the tennis ball can after heating with single and double glazing. It should be roughly 2X with single versus double due to R-1 versus R-2. This procedure can be used to demonstrate, in a crude way, the effect of double glazed thermopane units on heat loss.

BIBLIOGRAPHY - CHAPTER SEVEN

Mid-Atlantic Solar Energy Association, Proceedings of the 2nd National Passive Solar Conference, Vol. II, "Components Simulation and Testing", pp. 305-347.

This section presents ten research reports on windows and window treatments. This information gives a good picture of the types of activities currently underway.

Shurcliff, William, Thermal Shutters and Shades: Systematic Survey of over 100 Schemes for Reducing Heat-Loss Through Large, Vertical, Double Glazed, South Windows on Winter Nights, Cambridge, Mass., 1977, $12.00 paperbound.

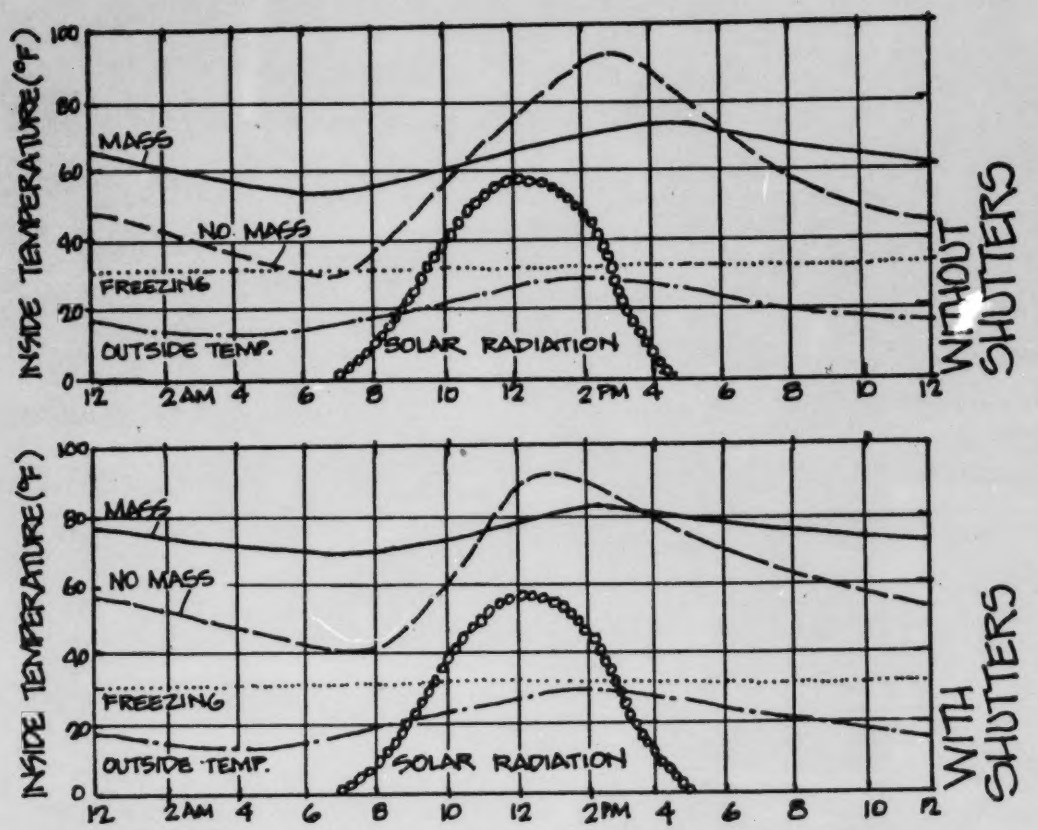
This survey focuses on specific schemes for insulating windows. The book offers a thorough, well-presented introduction to both the theory of heat loss through windows and the economics of window treatments. The heart of the book is the explanation of the myriad schemes devised to solve this critical design problem of window heat loss.

TEACHER NOTES

CHAPTER EIGHT: THERMAL MASS

1. The Effect of Thermal Mass. The addition of thermal mass helps to temper the swings in temperature with a solar structure. Use the Region #10 Vocational Greenhouse to show these effects. By adding 24,000 pounds of water, the excess energy within the greenhouse can be stored. The temperature in the greenhouse does not drop below 56°F. with the thermal mass. Without it, the inside temperature would drop below freezing, an intolerable situation. The extreme high temperatures are kept down also. Without thermal mass the temperature goes up to 88°F., but with it the maximum temperature is 68°F.

A further refinement comes with the addition of shutters of R-value 8. In addition, these shutters reflect up to 30% more radiation into the greenhouse. The effect of thermal mass and shutters can be seen in the graph on the following page.



PERFORMANCE OF REGION #10 GREENHOUSE

CLEAR DAY - JANUARY - 44°N LATITUDE

As with the shutter, the effect of adding thermal mass is significant. The end result is to flatten out the temperature swings. With the use of thermal shutters, which in this case are exterior reflectors as well, the increased solar radiation at around noontime is reflected in an earlier inside high temperature -- 1:30 p.m. with shutter and mass as opposed to 4 p.m. with no shutter and mass.

2. Heat Capacity. Finding heat capacity is a fairly direct computation. The heat capacity of a substance is determined by two variables: density and specific heat. Water is unique among substances on earth: it has the highest heat capacity (Qst).

Specific heat (c) is defined as the amount of heat needed to raise the temperature of one pound of a substance one Fahrenheit degree. The units of specific heat are BTU/lb.·^{o}F. Density (d) is the mass per unit volume, in the units of lb/ft^{3}. Qst = c x d. Use this equation to complete the following table. Leave numbers in parentheses out for students to fill in.

Material	Specific Heat (c)		Density (d)		Heat Capacity
	c	x	d	=	Qst $\frac{BTU}{ft^{3}{}^{o}F.}$
Brick	.20	x	120	=	24
Concrete	.23	x	(150)	=	34.5
Steel	.12	x	490	=	(58.8)
Water	1.0	x	(62.4)	=	62.4
Wood	.67	x	32	=	21.4

3. Latent Heats. When substances undergo phase change (i.e. ice melting to water), a large amount of heat is either absorbed or liberated. As water changes from ice to a liquid at 32°F., about 144 BTU per pound must be added. In other words, the latent heat of water must be supplied in order to effect a change of phase.

Throughout the country exciting research is being conducted on the topic of latent heat storage panels. Collecting systems have been designed which use eutectic salts which undergo phase change at around room temperatures. This physical characteristic allows these eutectic salt storage materials to hold 10-20 times as much heat on a volume basis as sensible heat storage materials.

Write to the following laboratories to request information on phase change storage materials. Compare material results. What seem to be the major barriers to widespread use of phase change materials?

1. Maria Telkes
   c/o American Technological University
   Killeen, Texas 76541

2. Institute of Energy Conservation
   University of Delaware
   Newark, Delaware 19711

3. Massachusetts Institute of Technology
   Department of Architecture
   Massachusetts Avenue
   Cambridge, Massachusetts 02142

BIBLIOGRAPHY - CHAPTER EIGHT

Kreith, Frank and Jan Kreider, Principles of Solar Engineering.
This book contains several sections which deal directly or indirectly with thermal mass. Just about everything you need to know is contained in the main text or appendices.

Mid-Atlantic Solar Energy Association, Proceedings of the 2nd National Passive Solar Conference, Vol. I.
State of the art papers on this topic, both for sensible heat storage and phase change.

Wright, David, Natural Solar Architecture: A Passive Primer.
To me the author's style of presentation is concise and clear, particularly his sections on thermal mass. The drawings help to explain basic principles in a way completely different from an advanced engineering text.

TEACHER NOTES

CHAPTER NINE: MASS WALLS

1. Pueblo Structures of the Southwest. As early as 1100 A.D. various Indian tribes (the Pueblos, Anasazi and Sinaqua) of the American Southwest built clustered houses using adobe, mud and brick. These materials are once again being used because of their thermal qualities and low cost.

Research the histories of these various Indian tribes. What attitudes did these peoples have regarding the land, their dwellings, and the natural environment? Are the same building techniques in general use today? Locate any and all references having to do with the heating and actual construction of these structures. Comment on the use of locally available materials. What can we in Maine learn from these ingenious peoples?

2. Domestic Technology Institute's Solar Forced Air Heater. The Domestic Technology Institute is located in Evergreen, Colorado. This group has done excellent work in low-cost community based solar design. One solar retrofit they strongly advocate is a simple wood frame solar forced air heater. A set of excellent plans is available from them for $7.50. These plans include detailed construction steps, materials list, and basic theory. Write to DTI, Box 2043, Evergreen, Colorado 80439.

3. Trombe Wall Aesthetics. In the fall of 1977, Northeast Carry petitioned the Hallowell, Maine, Zoning Board for permission to erect a Trombe wall retrofit. Their building possesses a south-facing brick wall that is not obstructed by neighboring buildings. The Zoning Board turned down their request on the grounds that the Trombe wall would detract from the historic value of the building and would, in general, be an eyesore for the entire community. Obtain the February 24, 1978 issue of Maine Times for an article on this subject.

To what extent can buildings be retrofitted with Trombe walls without compromising aesthetics? Design a residence using a mass wall that retains good lines. For ideas on mass wall aesthetics, write to the College of the Atlantic, Bar Harbor, Maine 04609. Ask for descriptive literature on their school's solar dwellings.

4. Natural Thermosyphon. Collect sketches of the south walls of at least ten houses. Design Trombe wall retrofits for each of these structures. How can existing windows or vents be used to achieve a natural thermosyphoning?

The formula for determining air flow is $S = 8.8\sqrt{H \times \Delta T}$ where S = speed of air in feet/min, H = the vertical distance between air intake and air outlet, and ΔT = the difference in temperatures at outlet and inlet in $F.^{o}$ Use this equation to determine the natural flow rates for the ten houses. Assume

a ΔT of 20 F.^{o} Use the actual heights of the individual examples. Compute the flow rates. Next, compute the volumes of air flow by multiplying the areas of window or vent openings by the rates of flow.

If the Trombe wall system uses the bottom portion of two windows, each of 6 sq. ft. in opening, then the volume of air will equal:

$$S = 8.8 \sqrt{h \cdot 20} \text{ ft/min}$$

$$S = 39.4 \sqrt{h} \text{ ft/min}$$

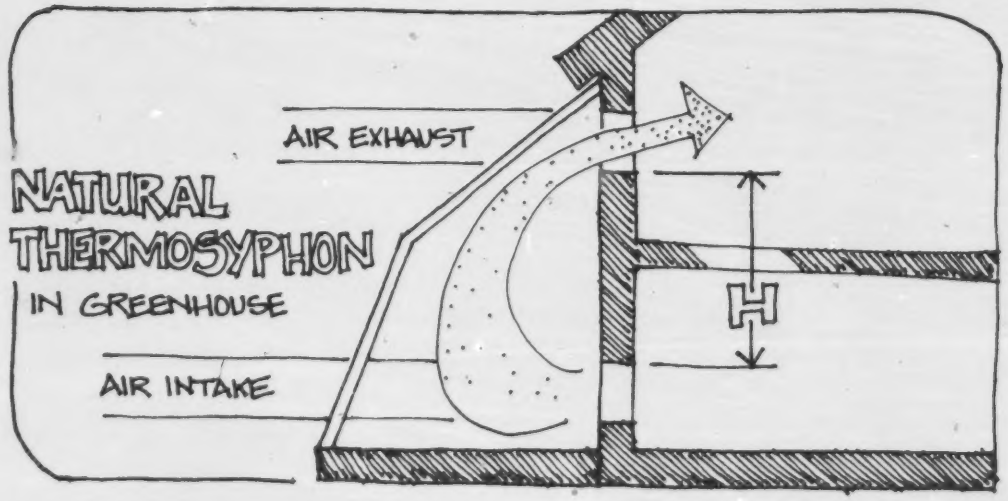
$$\text{volume} = S \times \text{Area}$$

$$\text{volume} = 39.4 \sqrt{h}^{\text{ft/min}} \times \text{Area}$$

In this case area = $2 \times 6\text{ft}^2$ or 12ft^2

$$\text{volume} = 39.4 \sqrt{h}^{\text{ft/min}} \times 12\text{ft}^2 =$$

$$\text{volume} = 472.8 \sqrt{h}\ \text{ft}^3/\text{min}$$



BIBLIOGRAPHY - CHAPTER NINE

Mid-Atlantic Solar Energy Association, Proceedings of the 2nd National Passive Solar Conference, Vol. I.

Again, this collection of papers says it all.

TEACHER NOTES

CHAPTER TEN: SOLAR GREENHOUSES

1. Consumer Attitudes. Because the idea of attached solar greenhouses is so new, consumer attitudes must be carefully evaluated. What type of greenhouse geometry do most people want? How much are they willing to pay? How large should these structures be? What do people want them for: attractive, inexpensive space? growing plants? collecting heat? What type of glazing do people prefer?

These questions can become part of a detailed questionnaire that students can pass out and later tabulate. Whenever the school demonstrates its buildings or attends an energy fair, these questionnaires should be given to visitors. On the basis of the responses to these polls, students can design a greenhouse which is salable to the general public.

2. Commercial Greenhouse Retrofit. Commercial greenhouse growers are extremely interested in energy conservation. It is the cost of fuel that is forcing their prices up. Those growers who go to solar retrofit will have a definite competitive edge. Obtain the following booklets: "Energy Conservation and Solar Heating for Greenhouses" NR-AES-3, $1.50, by John W. Bartok, Jr., Extension Agricultural Engineering, University of Connecticut, Storrs, CT., and "The Long

Wood Program", University of Delaware, Newark, Delaware 19711, $3.75.

These two books explain a variety of techniques for thermally upgrading commercial structures. Many vocational schools also have commercial type greenhouses. Students can use their knowledge of solar retrofit to develop workable designs. As fuel prices rise and food costs soar, the solar engineered greenhouse will become common in the Northeast.

3. Light versus Heat. People want attached solar greenhouses for a variety of reasons. There exists much debate over the light needs of plants, particularly as they are affected by the optical properties of the "new" attached solar greenhouses. Originally, greenhouses were designed with full glass on all sides to let in as much light as possible. In the newer solar greenhouses dark-colored thermal mass absorbs the incoming solar radiation, making it unavailable to the plants.

It has been recommended that thermal mass be painted either blue or red, so that the reflected light would be of the most beneficial color (wave length). Have students compile lists of plants they would like to grow in a solar greenhouse. Next, compile data on the light requirements for these plants. What are their needs relative to wavelength, photoperiod and intensity? Is it probable that auxiliary lighting will be required? Write to manufacturers of Grow-Lights. Request information on their products relevant to the type of plant

growing you expect to do. Lastly, devise plant growth experiments which will allow you to determine what works best.

4. Maine Vocation Region #10 Solar Greenhouse. Since the spring of 1977 the Region #10 Solar Greenhouse has been in operation in Topsham, Maine. Built by students with assistance from the Cornerstones School in Brunswick, the solar greenhouse proves that these structures can provide a healthy growing environment.

A copy of the Region #10 Solar Greenhouse booklet can be obtained from the Maine State Department of Education, Augusta, or from the Maine Audubon Society, 118 U.S. Route One, Falmouth, Maine 04105. This document explains the basic concepts of design and construction. In addition, it makes specific recommendations for vocational educators who want to set up a similar unit. The Region #10 Greenhouse has about 384 square feet of floor space, enough room for a small class (about 20 students).

5. Commercializing the Attached Solar Greenhouse. More than 100 people have expressed interest in building attached solar greenhouses in the Brunswick/Bath area alone. Cornerstones has undertaken a project with the Northeast Solar Energy Center (NESEC) in Boston to work with contractors in the area to devise an inexpensive prototype (i.e. around $2500 for both materials and labor). This structure will be analyzed for thermal per-

formance. Detailed records will be kept of construction costs (time and materials). Plans and results of the project will be available from NESEC, 70 Memorial Drive, Cambridge, MA 02142, or from Cornerstones, 54 Cumberland Street, Brunswick, ME 04011.

BIBLIOGRAPHY - CHAPTER TEN

Fisher, Rick and Bill Yanda, The Food and Heat Producing Solar Greenhouse, Santa Fe, New Mexico, John Muir Publications, 1976, $6.00, 162 pages.

This book provides an excellent overview which includes basic design theory, construction processes and plant growing techniques. In addition, the book includes a fascinating state of the art section which includes photos and drawings of about a dozen individual greenhouses, mostly in the Southwest. Also, this section contains descriptions of research groups and manufacturers of greenhouses and components.

Gorham, Jonathan, Vocational Region #10 Solar Greenhouse, Falmouth, Maine, Maine Audubon Society, 1978, $4.50, paperbound.

This booklet offers a detailed explanation of the attached solar greenhouse built at the Vocational School in Topsham, Maine. The booklet explains basic theory as well as presenting recommendations for the teaching of solar energy through the construction and use of a solar greenhouse.

Hayes, John, Energy Conserving Solar Heated Greenhouses, Marlboro, Vermont, 1977, 282 pages.

This volume contains more than 35 papers and speeches delivered at the Marlboro conference. The papers describe a wide variety of relatively

low-cost, low-technology solar greenhouses. An abundance of useful technical information and a philosophical overview are contained in these proceedings. Available for $9.00 from Maine Audubon Society or Marlboro College.

McCullagh, James C., editor, The Solar Greenhouse Book, Emmaus, Pennsylvania, Rodale Press, 1978, $8.95, 328 pages.

This work is more comprehensive than the Fisher book, containing excellent chapters on solar physics and greenhouse design. The information in this book provides sufficient introduction to heat loss and solar gain calculations. The book also explains the advantages of various greenhouse types and explores a variety of growing pod- or mini-greenhouse alternatives. Approximately one third of the book is devoted to managing a solar greenhouse.

Washington State Office of Public Instruction, Energy, Food and You, two levels: K-6 and 7-12, Seattle, Washington, 1977, $5.00 each.

These books provide a wealth of practical classroom ideas on the topics of alternate energy, appropriate technology and nutrition. This book uses effective, low-cost experiments and demonstrations to teach key energy/food concepts.

TEACHER NOTES

CHAPTER ELEVEN: ACTIVE SOLAR

1. Collector Aesthetics. Many homeowners think that the addition of flat plate collectors will detract from the appearance of their houses. Collect pictures from magazines, newspapers and journals. Have students devise a rating system for the evaluation of active solar aesthetics. After a number of houses have been judged, students can evolve a set of principles for installing collectors, methods by which the appearance of the structure is not compromised. Use some of the slides from Chapter 11 to elicit student opinions on solar aesthetics. A larger question the students can ponder is: should functionality come before aesthetics?

2. Flat Plate Collector Components. It is essential that students understand the workings of a flat plate collector. Ask students to bring in materials from which model flat plates can be manufactured: old refrigerator coils, foil-faced insulation, rectangular insulated boxes, old storm windows or plastic films, copper tubing, recycled hot water tanks, etc. Students should have a collection of scrounged parts from which experimental models can be put together.

Use the book Solar Dwelling Design Concepts for ideas on collector design. Encourage students to design experiments to elucidate the following design problem areas:

1) Heat transfer between absorber plate and tubing. What configuration is best? (e.g. tubes glued onto the absorber backing? Soldered? Form fitted?)

2) Color of absorber plate and use of selective surfaces. Try various types of paint: Rustoleum, "Hibachi Black", gloss black enamel, stove polish.

If possible, secure a selective surface coating material like black chrome. Can appreciable differences between the various coatings be demonstrated? It is essential that test conditions be identical. This effect can be achieved by placing identical units (except for the experimental variable) side by side. In doing any of these comparison tests, it is necessary to ensure similarity of experiment conditions. It is possible that only gross differences in performance will be noticeable depending on the degree of sophistication of the experiment.

3) Dissimilar metals in contact with one another. It is imperative that dissimilar elements (copper and aluminum) do not come into contact with one another. Flat plate collector manufacturers have taken great care to avoid this situation. Have students write to collector manufacturers asking about this particular problem. How does their unit avoid this situation? Are there specific recommendations for installers regarding dissimilar metal couplings?

3. Northeast Carry Poster. Ron Poitras of Northeast Carry has assembled a wealth of information on a large poster. These two-sided posters are available from Northeast Carry,

110 Water Street, Hallowell, Maine 04328, for $2.50 each, or $1.80 in quantities over five. They are also available from the Office of Energy Resources, Augusta, Maine 04333.

Have students write to the manufacturers and distributors of various collectors. Assemble this data to cross-check and update the information contained in the poster. Are there any new technological breakthroughs which significantly affect the performance or cost of current systems? Have students write to AETA, Solar, Inc., P.O. Box 452, Durham, N.H. 03824 to obtain the latest information on phase change - freon charged units. Are there any new absorber paints or selective coatings available? What are the tradeoffs (performance vs. price) of owner-built units with commercial ones?

4. Life Cycle Costing. Life cycle costing is a means of computing the total cost of a system or product over the course of its lifetime. If people made decisions based on total life cycle cost, then alternate energy products in general and conservation measures in particular would be in greater demand.

Have students price a standard 1200 square foot L.C. Andrew house with three options: a) electric baseboard, b) oil furnace, and c) active solar space heating. Define the thermal characteristics of the building first. Then get quotes on the various costs. In order to do a life cycle costing analysis, the following additional data needs to be collected: fuel, maintenance and insurance costs per year. If we assume a 20-year life of

each system, then the total life costs can be computed. Fill in the following table: (approximate costs are in parentheses)

Heating System	Life of System in years	Total Annual Operational Cost*	20-Year Operational Cost
electric	20	(1000+10+50) = 1060	$ 21,200
oil	20	(500+50+50) = 600	12,000
solar	20	(120+100+50) = 270	5,400

	20-Year Operational Cost	+	Initial Cost	=	Total Life Cycle Cost
electric	$ 21,200	+	800	=	$ 22,000
oil	12,000	+	2500	=	14,500
solar	5,400	+	8000	=	13,400

This very simple example does not take into consideration the assumed increase in the cost of all fuels or the cost of a back-up heating system for the solar installation.

Students can perform similar life cycle costing analyses on such products as similar volume food freezers or similar capacity air conditioners. Choose products that have large initial price differences but contrasting efficiencies.

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*The Total Operational Cost equals the fuel, maintenance and insurance costs. The fuel for the solar system is the electricity needed to run pumps or fans.

BIBLIOGRAPHY - CHAPTER ELEVEN

Kreith, Frank and Jan Kreider, Principles of Solar Engineering. This book contains all the necessary information. The challenge is to cull it out from the jumble of mathematical equations.

Watson, Donald, Designing and Building a Solar House; Your Place in the Sun, Charlotte, Vermont, Garden Way Publishing, 1977, $8.95 paperbound.

This book is filled with diagrams and photographs. It offers many ideas for the integration of active solar systems with passive solar structures. Two chapters are devoted exclusively to active systems. This book introduces the basic concepts of active solar, whereas the Kreith and Kreider text tells you in precise engineering terms what is theoretically going on.

TEACHER NOTES

CHAPTER TWELVE: SOLAR HOT WATER

1. Northeast Carry Poster "Constructing the Collector". This poster contains a wealth of information above and beyond the instructions for building a flat plate collector. For example, the poster lists principal types of collectors, their advantages and disadvantages, different collector and storage tank arrangements, and, most importantly, the names and addresses of solar equipment dealers in Maine. Obtain the poster from Northeast Carry, Hallowell, Maine 04347, or from the Office of Energy Resources, Augusta, Maine, 04333.

Do an update of the list of dealers of solar equipment in Maine. Contact each one to get copies of the latest sales literature, and to find out about new systems and installation tips. Do a comparison of the various commercial units available. Collect as much information as possible in order to make fair comparisons.

2. Maine State Solar Hot Water Initiative. In 1977 the Maine State Legislature appropriated $16,000 to help finance 40 solar hot water units. Maine was the only New England state not included in the H.U.D. hot water program. The state was excluded because of Maine's relatively low electricity prices (due to Maine Yankee). Because of our state's low ground water tem-

perature, however, we end up spending more to heat our water than do the citizens in several other New England states. Maine's hot water program seems to be working well. Contact Vincent DiCara at the Office of Energy Resources for information on these 40 specific installations. Ask for any evaluations that have been done to date. Is it fair to draw conclusions at this point? How many of the 40 units were manufactured within the state? What were the professional and educational backgrounds of the people who installed the systems? Compile a list of lessons learned by the installers during this program.

3. Behavioral Objectives: Solar Hot Water Curriculum. As originally conceived, this solar curriculum was meant to have as its central focus the training of solar hot water technicians. Because solar energy presupposes energy conservation and total system design, however, we came to feel this original focus was too narrow. The New England Fuel Institute's Solar Education Division (20 Summer Street, P.O. Box 888, Watertown, Massachusetts 02172) now offers an excellent 10-week course on the specific topic of solar hot water system installation. Write to them for their latest information.

The following objectives are those originally proposed for a two-year course at PRVTC which had as its main purpose the training of solar technicians.

PERFORMANCE OBJECTIVES

FIRST YEAR

After one year of study, each student should be able to:

1. Explain the nature of solar radiation in terms of types and amounts of energy available.
2. Distinguish between focusing and flat plate solar collectors.
3. Identify and explain the function of each of the key components of a flat plate collector.
4. Use a sun angle chart to locate altitude and azimuth angles.
5. Locate due south using compass or solar noon chart.

TECHNICAL SKILLS

1. Identify fittings by sight, e.g. different metals and different I.D.'s and O.D.'s.
2. Learn how to dig holes and trenches safely.
3. Solder, using propane, mapp and air acetylene torches.
4. Cut, sand, and properly dope copper tubing.
5. Penetrate standard masonry and wood walls (for collector lines).
6. Insulate piping.
7. Apply urethane and styrofoam insulation to tanks and walls.

SECOND YEAR

After the second year of course study, students should be able to:

1. Utilize the cosine loss angle formulas to size collector arrays.
2. Discuss the solar constant with regard to available solar energy.
3. Explain use of meteorological instruments for measuring availability of solar energy.
4. Discuss the technological problems confronting each of the various solar technologies.
5. Explain H.U.D. performance standards for solar hot water systems.
6. Identify and discuss those areas of greatest technical debate concerning collector design.
7. Discuss the cost and performance characteristics of different types of insulation.
8. Understand the dynamics of heat flow and the basic laws of thermodynamics.
9. Document through experimentation the effects of ultraviolet degradation as it relates to glazing, insulation and cover decay.
10. Calculate heating loads for a particular structure.
11. Compute solar gain through glazings of different solar orientations.

12. Calculate the load due to weight of collector array on roof.

TECHNICAL SKILLS

1. Design and weld a stand for collector array.
2. Change refrigeration lines.
3. Design and build an insulated protective cover for a heat storage area.
4. Design and solder together a pipe run from collector to storage.
5. Wire a 110V Y12 water pump to plumbing and electrical code specifications.
6. Batch foam a septic tank storage tank with urethane foam.
7. Build from components a functioning flat plate collector.
8. Hook up relay valves for different thermostatic zones.
9. Apply and use a thermocouple.
10. Participate in at least one complete installation of a solar hot water system from design to functioning stages.

4. AETA, Helio Phase Solar Hot Water System. This phase change system uses Freon® 114 as its transfer medium. Unlike the majority of commercial systems, this one is passive in that it uses no external power to operate. It relies on the sun to heat up the liquid Freon® 114. As the liquid boils, it changes to a vapor which rises to a heat exchanger within the water tank. Once the vapor gives up heat, it returns to its liquid state and returns to the collectors to recycle.

According to the manufacturers, the system is completely self-controlled, very efficient, less expensive, without moving parts, and fail-safe. Write to AETA Solar, Inc., P.O. Box 452, Durham, New Hampshire 03824.

5. Heeschen Inverted Solar Water Heater. Conrad Heeschen is a solar designer and author living in Dryden, Maine. He has developed an inverted solar hot water heater. This do-it-yourself collector is simple to build. The cost of a 16' long unit is about $350. Each unit can deliver about 50,000 BTU during a clear winter day in northern New England. See pp. 632-636 in the Second Passive Solar Energy Conference Proceedings from Mid-Atlantic Solar Energy Association, 2233 Gray's Ferry Avenue, Philadelphia, Pennsylvania 19146. $20.00 for 3 volumes. Or write to Conrad Heeschen, Sunsystems, Dryden, Maine 04225.

BIBLIOGRAPHY: CHAPTER TWELVE

Campbell, Stu with Doug Taff, Build Your Own Solar Water Heater, Charlotte, Vermont, Garden Way Publishing, 1978, $4.95 paperbound.

This book contains a fairly comprehensive treatment of many of the major design problems solar installers face. The book stresses the need for hot water conservation. Despite a number of technical errors (e.g. the definition of a Langley is incorrect), this work offers a solid general background to solar hot water systems.

CURRICULUM OBJECTIVES

After study of each chapter in Solar Concepts, students should be able to:

Chapter One: Energy Lingo

-- demonstrate understanding of key energy terms, e.g. BTU, kWh, Joule, calorie, Watt, etc.
-- explain the difference between energy and power.
-- convert from one energy or power term to another.
-- demonstrate understanding of exponential notation.
-- identify various energy forms.

Chapter Two: Renewable versus Non-Renewable Energy Sources

-- explain the difference between renewable and non-renewable energy sources, and cite examples of each.
-- list the three common fossil fuels and describe the nature of our dependence on each.
-- explain why nuclear fission power is "non-renewable".
-- describe how Maine's energy supply differs from that of the United States as a whole.
-- list the numerous benefits of switching to renewable energy sources.
-- explain the significance of exponential growth as it relates to the energy crisis.

Chapter Three: History of Solar

-- cite examples that show that solar energy applications are decades old.
-- understand how one energy source has replaced another through history.
-- explain how our choice of energy technologies reflects our feelings toward the natural environment.

Chapter Four: Quantifying the Solar Resource

-- define altitude and azimuth angles.
-- use a sun angle chart.
-- explain where in the contemporary picture solar can displace conventional energy sources.
-- cite facts describing the vast amount of solar energy available.
-- explain problems inherent in the collection of this vast amount of energy.
-- define "solar constant".
-- distinguish between and list examples of natural and technological solar collection.

Chapter Five: Heat Transfer

-- explain concept of R-value.
-- define the three methods by which heat is transferred and give examples to illustrate an understanding.
-- compute Degree-Days for one day, and for an entire heating season.

Chapter Six: Passive Solar

-- distinguish among passive/hybrid/active solar systems.
-- explain the three basic passive solar design concepts.
-- explain importance of site conditions and selection.
-- describe proper window placement and treatment.
-- list examples of general types of passive solar systems.

Chapter Seven: Windows as Solar Collectors

-- describe function of windows in passive solar design.
-- explain that the "greenhouse effect" in buildings is due to stoppage of convection heat loss rather than the opacity of the glazing.
-- explain how the earth's atmosphere creates its own "greenhouse effect".
-- list four common solar retrofit options.
-- describe the function and potential savings of window shades and shutters.

Chapter Eight: Thermal Mass

-- explain the function of thermal mass within a passive solar system.
-- use the formula: heat capacity (Qst) = specific heat (c) x density (d). (Qst = c x d)
-- explain the difference between sensible and latent heat storage.
-- cite three key rules of thumb for design of a structure's thermal mass.

Chapter Nine: Mass Walls

-- distinguish between integral and free-standing mass walls.
-- distinguish between masonry and water mass walls.
-- explain the basic theory of a mass wall's operation.
-- describe the variety of mass wall material and placement options.
-- describe mass wall retrofit possibilities.
-- cite examples to show that mass walls are not new.

Chapter Ten: Solar Greenhouses

-- list benefits of solar greenhouses.
-- explain how solar greenhouses differ from conventional ones.
-- explain the difference between and advantages of direct feed, water wall and indirect storage solar greenhouse types.
-- describe the process of natural thermosyphoning.
-- explain the relationship between inside temperature fluctuation and thermal mass.
-- list nine general rules of thumb for solar greenhouse design.

Chapter Eleven: Active Solar

-- understand the concept of solar tempering.
-- explain "life cycle cost" analysis.

-- identify and explain the function of the major components of a flat plate collector.
-- describe the components of the three basic types of collector systems.
-- distinguish between concentrating and flat plate collectors.

Chapter Twelve: Solar Hot Water

-- cite examples to show that solar hot water is not new.
-- explain significance of hot water conservation and solar water heating.
-- distinguish between closed-loop, drain down, and Freon hot water systems.
-- list advantages and disadvantages of each type.
-- explain the function of absorber plate selective surfaces.
-- describe the workings of three alternative solar hot water systems: bread box, thermosyphon, and solar greenhouse preheat.

QUIZ ONE - SOLAR OVERVIEW

Name _____ Score _____

Date _____ Class _____

Please answer the following questions. This is not an exam. This quiz is meant to help us evaluate how much you already know about solar energy. You are not expected to know all of the answers.

True or False (circle correct answer)

1. T F The sun is closer to the earth in the winter than it is in the summer.
2. T F During the winter in Maine, more solar energy strikes a vertical wall collector than strikes a horizontal collector of the same size.
3. T F During the course of the year the sun never rises north of due east in Maine or sets north of due west.
4. T F In general, passive solar systems are more expensive than active ones.
5. T F Solar hot water heaters have been in use since before 1920.
6. T F Each year more solar energy falls on the roof of an energy-efficient house than is needed to power it completely.
7. T F KiloWatt-hour (kWh) is a unit of power.

8. T F Heat is a measure of the intensity of molecular vibration.

9. T F For efficient solar collection, we want high heat, not high temperature.

10. T F Maine is heavily dependent on oil for its energy supply.

There are three basic methods of heat transfer: conduction, convection, and radiation. Define each term and give an example to illustrate each:

11.

12.

13.

14. If the high temperature for a winter day is 22°F. and the low is 12°F., how many Degree-Days are accumulated for that day? _____

15. Calculate the heat loss through an insulated wall (R = 14). Assume an inside temperature of 65°F. and an outside temperature of 25°F. The surface area of the wall is 100 sq. ft.

List the major functions of thermal mass within a passive solar structure:

16.

List the three components of a flat plate collector and explain the function of each:

17.

18.

19.

20. What is the purpose of a selective surface coating on a flat plate collector absorber plate?

QUIZ TWO - CHAPTERS 1-3

Name _____ Score _____

Date _____ Class _____

Match up each of the following energy terms with its correct definition: (write the letter of the definition only)

term	definition	term	definition
1. altitude	_____	6. power	_____
2. azimuth	_____	7. heat	_____
3. conduction	_____	8. temperature	_____
4. convection	_____	9. infrared	_____
5. energy	_____	10. ultraviolet	_____

definitions

a. the total amount of thermal energy a body possesses.

b. that part of the electromagnetic spectrum below the red band of visible light.

c. the transfer of heat due to the interaction of neighboring molecules.

d. the application of a force through a distance, or the ability to cause change.

e. the angle formed by an object overhead and the horizon.

f. energy used per unit time.

g. a measure of the energy of motion of the atoms and molecules of a substance.

h. the part of the electromagnetic spectrum beyond the violet band of visible light.

i. the angle formed by the projection of a line to an object onto a horizontal plane and by a true north/south line.

j. the transfer of heat by a moving fluid, usually air or water.

11. Mathematically show why kiloWatt-hour (kWh) is an energy term.

12. If a bathtub contains 35 gallons of hot water at 110°F., how many BTU in total will be given off after 3 hours, once the water temperature has dropped to 70°F.?

List five common energy forms, and give an example or source for each:

	form	example or source
13.	_____	_____
14.	_____	_____
15.	_____	_____
16.	_____	_____
17.	_____	_____

Match up the following energy units with the appropriate quantities:

Joules calories kiloWatt-hours BTU quads

18. 200 _____ in a Hershey bar.

19. 73 _____ used by the U.S. in 1973.

20. 1000 _____ in a match.

21. 600 _____ used each month by an average Maine household.

22. 100 _____ in a cup of hot coffee.

23. If there are about 10^6BTU in one barrel of oil, and 10^3BTU in a jelly donut, how many times more energy is available from the oil?

Label each of the following energy sources as either renewable (R) or non-renewable (NR):

24. nuclear _____

25. wind _____

26. solar _____

27. coal _____

28. hydropower ____

Circle the correct answer:

29. T F Maine is heavily dependent on oil.

30. T F Nearly 63% of our state's oil comes from foreign sources.

31. T F In exponential growth, the last term is smaller than the sum of all the terms which came before it.

32. T F Solar energy systems have been in operation since before 1900.

33. T F The major source of energy for the U.S. has shifted several times during the past century.

34. T F A quad is equal to a mQ, or 1/1000 Quintillion BTU.

QUIZ THREE - CHAPTERS 4-6

Name _____ Score _____

Date _____ Class _____

Circle the correct answer:

1. T F In one year 5000 times more solar energy strikes the earth than comes from the combined total of all other energy sources.
2. T F A solar furnace has achieved temperatures in excess of 8000°F.
3. T F The total solar energy striking the U.S. in one year is equal to one million times the energy output of an average electrical power plant.
4. T F It is more important to place window shades or shutters on north-facing windows than on those facing south.
5. T F The sun is closer to the earth in the winter than it is in the summer.

List three factors which limit the amount of collectable solar energy:

6. _____
7. _____
8. _____
9. According to ERDA officials, what percentage of our country's energy could be supplied by solar energy by the year 2020? _____

Draw a flagpole situated so that its top forms a 45^{o} altitude angle and is 15^{o} east of south from a central observation point:

10.

11.

List and define three methods of heat transfer:

12.

13.

14.

Explain which method of heat transfer each of the following examples illustrates: (choose either conduction, convection, or radiation)

15. a frying pan _____

16. a forced hot air furnace _____

17. a woodstove _____

18. the sun _____

19. an iron _____

20. a heat reclaimer in a woodstove stack _____

Match up the following materials with the appropriate R-values: (fill in the correct letter)

a) R-1 b) R-5.2 c) R-11 d) R-19 e) R-2

	material	R-value
21.	6" fiberglass batt insulation	_____
22.	single pane of glass	_____
23.	3½" fiberglass batt insulation	_____
24.	double panes of glass	_____
25.	1" of styrofoam	_____

26. If the high temperature for a winter day is 32^{o}F., and the low is 18^{o}F., how many Degree-Days are accumulated for that day? _____

27. Calculate the heat loss through an uninsulated wall section of R-4. Assume a ΔT of 45^{o}F. and a wall surface area of 86 sq. ft.

28. A solar building captures 25 times more energy over the course of a year than it uses in electricity to run the system. This system is classified as either a) passive, b) hybrid, or c) active. (Circle correct answer.)

List three basic passive solar design principles and describe a system which demonstrates the use of each:

29.

30.

31.

Describe three site conditions which must be analyzed when designing a passive solar system:

32.

33.

34.

QUIZ FOUR - CHAPTERS 7-9

Name _____ Score _____

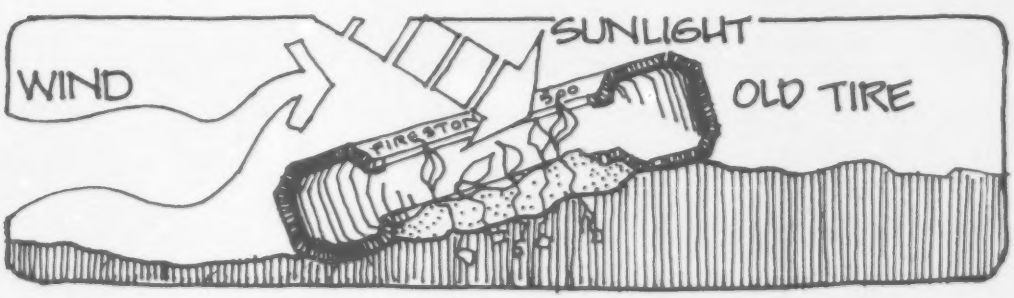
Date _____ Class _____

List the two functions windows are asked to perform, and explain why other devices are called for:

1.

2.

Explain how the Blackstone recycled tire greenhouse illustrates the true "greenhouse effect". (See illustration.)



3.

4. Why does the outside air temperature drop way down on a clear winter night?

What is the function of thermal mass within a solar structure? List two possibilities:

5.

6.

7. Define latent heat and explain its advantage over sensible heat storage.

Use the solar greenhouse rules of thumb to determine the quantity of thermal mass needed for a solar greenhouse of 365 sq. ft. of south glazing:

8. weight of rocks _____

9. volume of water _____

10. If stone has a specific heat (c) of 0.2 and a density (d) of 165, its heat capacity (Qst) equals _____.

Circle the correct answer:

11. T F Water has the highest heat capacity of any substance on earth.

12. T F In determining the thermal mass of a house, the furniture and rugs cannot be included.

13. T F On a volume-for-volume basis, masonry offers better thermal mass storage capability than water.

14. T F An integral mass wall does not have to be part of the building structure.

15. T F Mass walls must be attached to the roof or walls of a building structure in order to be effective.

16. T F Mass walls can be used for building retrofit.

17. T F Reverse thermosyphoning is a design problem yet to be solved.

18. T F The use of insulation between mass wall and glazing is always cost effective.

19. T F A mass wall was constructed prior to 1900.

20. T F Mass walls only transfer heat by conduction.

List and explain three basic mass wall types:

21.

22.

23.

Draw a diagram to explain air flows in a typical mass wall.

24.

Fill in the following table:

	substance	specific heat	x	density	=	heat capacity
25.	adobe	0.22		_____		20
26.	brick	0.2		120		_____
27.	concrete	_____		150		34.5
28.	steel	.12		490		_____
29.	water	1.0		_____		62.5
30.	wood	_____		32		10.6

Thermal mass storage systems should be designed with the following design principles in mind:

31.

32.

33.

Name a specific substance or type of material used for latent heat storage:

34.

QUIZ FIVE: CHAPTERS 10-12

Name _____ Score _____

Date _____ Class _____

List three common uses for attached solar greenhouses:

1.

2.

3.

4. Solar greenhouses differ from conventional ones in all of the following ways except that they (circle correct answer) a) require greater structural support for the glazing; b) use some form of thermal mass; c) rely on escaping heat to melt snow from the glazing; d) require an insulated north wall and roof.

Draw a diagram of each of the basic solar greenhouse types, and explain the working principles of each (direct feed, water wall, and indirect storage):

5.

6.

7.

Circle the correct answer:

8. T F The greater the amount of thermal mass in a solar greenhouse, the greater the fluctuation in temperature will be.

9. T F Sono-buoy cases make good thermal mass water containers.

10. T F A solar greenhouse can be oriented 45^{o}-90^{o} off from direct south without paying a big price thermally.

11. T F Solar greenhouse foundations should be insulated to below frost line.

12. T F 100% solar space heating in Maine is generally cost effective.

13. T F There is no fuel cost associated with an active solar system.

14. T F Concentrating collectors are best suited for areas which receive substantial amounts of direct sunshine.

15. T F The major cost of an active solar system is in the initial installation price.

16. T F No solar hot water systems were sold before 1900.

17. T F The average hot water temperature in American homes is 180°F.

18. T F With tax credits and demonstration grants of $400, solar hot water systems are cost effective in the Northeast.

19. T F Site-built collectors are always more expensive than comparably sized commercial units.

20. T F It is not cost effective to build a house that gets only 40%-60% of its space heat from solar.

Explain the function of each of the following components of a flat plate collector:

21. glazing

22. absorber plate

23. fluid or air grid

24. insulation

25. casing

List the advantages and disadvantages of each of the following basic types of active systems:

26. closed loop anti-freeze

27. water trickle

28. air

29. If an average American family uses 20 gallons of hot water per person per day, and the cost of supplying that amount is 15¢ per day, how much money could be saved by a family of four over a one year period if they installed hot water conserving devices that cut their consumption in half?

Define absorptivity and emissivity, and explain how these two phenomena determine which materials make effective selective surface coatings:

30. absorptivity

31. emissivity

A good selective surface has a (fill in the missing word)

32. _____ absorptivity and a

33. _____ emissivity.

34. Name one potential danger of a drain down solar hot water system:

QUIZ SIX - FINAL EVALUATION

Name _____ Score _____

Date _____ Class _____

1. The earth travels around the sun in an elliptical orbit. How does this orbit affect the amount of solar energy received by the earth at its outer atmosphere?

2. Define the Solar Constant.

3. The earth receives about 6×10^{17} BTU/hour. Is this an energy statement or a power statement?

4. How many quads per hour does 6×10^{17} BTU/hour equal?

5. Explain the origin of the word "insolation".

What are the minimum and maximum solar altitude angles for Portland, Maine (44^{o}N. latitude)?

6. Maximum angle _____ date it occurs _____

7. Minimum angle _____ date it occurs _____

8. In general, why are water thermal mass storage systems more effective than masonry systems?

9. Mathematically show why kiloWatt-hour (kWh) is an energy term.

10. If the high temperature for a winter day is 28°F., and the low is 12°F., how many Degree-Days are accumulated for that day?

11. Explain the difference between latent and sensible heat storage.

List three common objectives of adding an attached solar greenhouse to an existing house:

12.

13.

14.

15. Why is nuclear fission power considered non-renewable?

Circle the correct answer:

16. T F There is about 1 BTU in an ordinary kitchen match.
17. T F The more thermal mass there is in a solar structure, the greater the temperature fluctuation will be.
18. T F The state of Iowa used about one quad of energy in 1976.
19. T F Many solar applications have been in use since before the 1950's.
20. T F Maine gets about 76% of its total energy from oil.
21. T F Stone has the highest heat capacity of any substance on earth.
22. T F Mass walls have been used in building retrofits.
23. T F Mass walls only transfer heat by conduction.
24. T F The heat capacity of a substance is determined by its specific heat and density.
25. T F A solar greenhouse can be oriented 45^{o}-90^{o} off from direct south without paying a great price thermally.

Bonus Question (5 points) If a six-pack of 16 oz. beers (one lb. each) is removed from the refrigerator where it was 45^{o}F. and sits on the kitchen table for 3 hours, it warms up to 65^{o}F. Over the course of those 3 hours, how many BTU were released to the room?

ALTIMETER

Introduction: Although extremely inexpensive, this altimeter can generate a wealth of useful information. A solar technician must understand thoroughly the use of this instrument. The altimeter is used to determine obstructions in the sun's path, a most critical design consideration.

Objective: To construct a workable altimeter for use in sun tracking and site evaluation.

Materials:

Quantity	Material	Price per unit	Total cost
2	1/16" screw eyes	$ .04	$ .08
1	1/8" x 12" x 12" masonite	.15	.15
1	plastic protractor	.29	.29
2	3/32" x 4" pan head wood screws	.02	.04
1	1/4" x 8" flat head wood screw	.02	.02
1	2" x 2" x 5" pine	.20	.20
1	can white spray paint	3.29	3.29

Equipment:

drill and 3/64" bit

protractor (for calibration)

band saw

compass

Procedure:

1. Trace an outline of the protractor 2 times on the 12" x 12" square piece of masonite to make two identical shapes. Cut these two pieces out and carefully sand all rough edges.
2. Cut out one "L"-shaped leg from the remaining masonite. (Refer to the diagram at the end of this project.)
3. Spray paint all of the pieces white and allow them to dry.
4. Calibrate the two protractor-shaped pieces. "0" degrees south refers to due south on the horizontal piece. The calibration on the upright piece is used to measure altitude angles.
5. Assemble the altimeter as illustrated in the diagram.
6. Drill holes in the top piece of masonite. Insert both 1/16" screw eyes. Align the screw eyes so that the tops form a scope (two holes) through which accurate readings can be taken.

Use:

1. With a compass, locate yourself where the solar installation is to go, and take a southerly bearing. (Remember to adjust for magnetic north.)
2. When you are holding the altimeter in your hand,

the vertical protractor containing the two screw eyes is used for determining altitude angles while the horizontal protractor with the south "0" indicator mark contains azimuth angle information. Direct the south indicator mark toward the southerly compass bearing, making sure to hold the base of the altimeter as level with the horizon as possible.

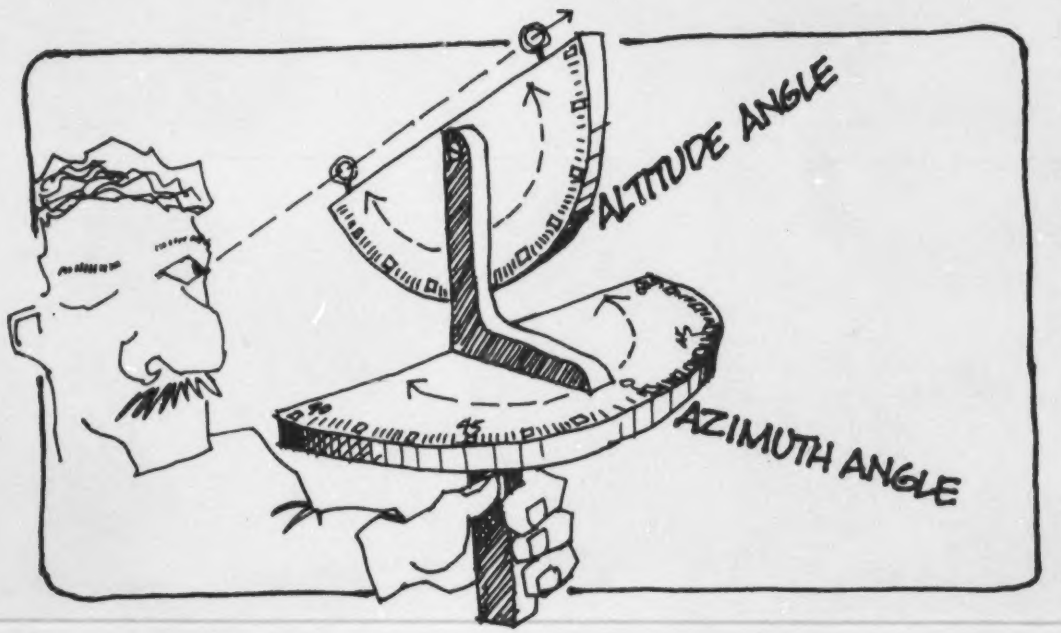
3. It is strongly recommended that a sun chart be used along with the altimeter. With the altimeter and an accurate sun chart, the student can easily determine which position the sun will assume in the sky on any given day throughout the year. This information would determine at what time of day the sun will appear above specific obstructions like trees or tall buildings. The information obtained will pinpoint the most suitable position in which to place the solar installation in order for it to receive the largest possible quantity of available sunlight.

Questions:

1. Why is it not necessary to calibrate the altimeter more than 90^{o} east or 90^{o} west of due south?
2. What considerations must be given to the type of nearby trees when siting for sun path obstructions?
3. Do you think that masonite is the best material

to use in making this altimeter? How would a choice of other kinds of materials affect the design of the altimeter?

4. Suggest other designs for the altimeter, e.g. with a scope, or a mirrored base. What kinds of designs are used by commercially available units?



SUN CHARTS

Introduction: An altimeter, a compass and a sun chart for the appropriate latitude form the basic tool kit for a solar technician. With these three items, a solar designer can determine how much sun will be available at any particular location. Accurate readings of sun charts can help determine which nearby trees must be sacrificed and which can be allowed to remain at any particular site.

Objective: To be able to determine the sun's location at any time of the day on any day of the year.

Equipment: Use the sun angle charts included.

Materials: None.

Procedure:

1. Choose the sun angle chart closest to your location (Brunswick, Maine is 44° North latitude; Caribou 47° North latitude.)
2. Place the chart in front of you and read off the markings on the outside of the largest circle (in this project, we use 44° North latitude as an example). You should begin with 0°, true south. Then read off 20°, 40°, 60°, Nov. 20, Oct. 21, etc. These outside markings represent the azimuth angle (the number of degrees

off from true south) and the day of the year.

3. Focus on 0° true south once again. Count the number of spaces from the outside circle to the center. How many spaces are there? These circles which share the same center measure the altitude angle of the sun (the angle formed by the sun overhead and the horizon). Since the sun can never be more than 90° (or directly overhead in the sky), this scale goes from 0° to 90°. Since there are 10 concentric circles going from the outside to the center, and the maximum altitude angle is 90°, each circle represents an increase of 9° (or $90 \div 10$).
4. Read off the value of each circle line starting from the outside, going in to the center. The first reading is 0° altitude, then 9° (not listed), 18° (listed) etc. Each circle represents an increase in 9° in altitude angle.
5. Locate the top curved dark line, labeled "hour of the day". Notice how the scale reads from 5 on the right of the chart to 7 on the left of the chart. Solar noon is not marked; it is represented by the center vertical line.
6. Count the number of curved "canoe" lines. There are seven such lines. Two months (December and June) are special in solar studies. On December 21, the sun is at its lowest point in the sky.

The longest day of the year occurs on June 21st. No other month shares this distinction. Other months can be paired because the sun traces a symmetrical path throughout the sky. It is for this reason that the opposing pairs of months (January and November, February and October, etc.) share similar "canoe" lines.

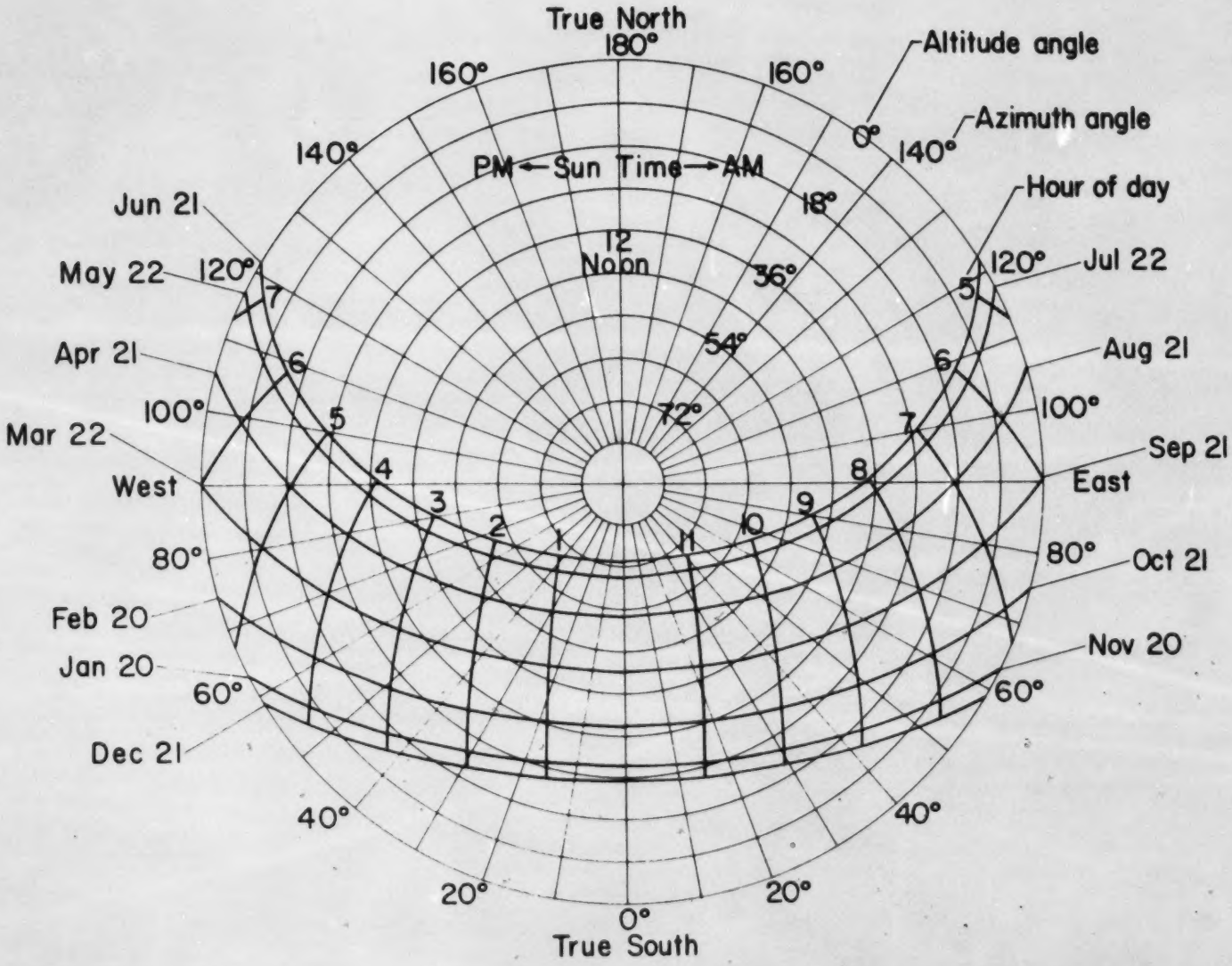
Use:

1. Locate the "canoe" line for October 21. Follow this line to azimuth angle = 0°, true south. Find the point where this "canoe" line crosses the 0° azimuth line. Starting from the outside circle, count the number of inner circles crossed until reaching the established point. Each time we cross another circle, the altitude angle reads 9° higher. What is the altitude angle for October 21 at solar noon at 44° North latitude?
2. Repeat the previous step for September 21. What is the altitude angle for this day? Altitude angles for days that fall between September 21 and October 21 can be determined by interpolation (measuring the proportional fraction between scales).

Questions: Now that you understand the basic operation of the sun charts, you should be able to answer the following questions. They are listed in order of difficulty. Select the correct chart for your latitude.

1. What is the altitude angle of the sun at solar noon on June 21?
2. What is the altitude angle of the sun at solar noon on December 21?
3. What is the altitude angle of the sun at solar noon on August 21?
4. What other month shares this same reading?
5. What is the altitude angle of the sun at solar noon on September 6?
6. What is the altitude angle of the sun at 10 a.m. on October 21?
7. What is the altitude angle of the sun at 4 p.m. on February 20?
8. What is the altitude angle of the sun at 1:15 p.m. on November 5?
9. What is the azimuth angle of the sun at 10 a.m. on September 21?
10. What is the azimuth angle of the sun at 3 p.m. on January 20?
11. On what day does the sun set at S 90^{o} W or due west?

12. At what time in the afternoon does the sun cross the east-west axis on May 22?
13. At which two times of the day is the sun at 45^{o} altitude angle on April 21?
14. When does the sun rise on July 4?
15. What are the altitude and azimuth angles of the sun at 6:15 a.m. on August 6?

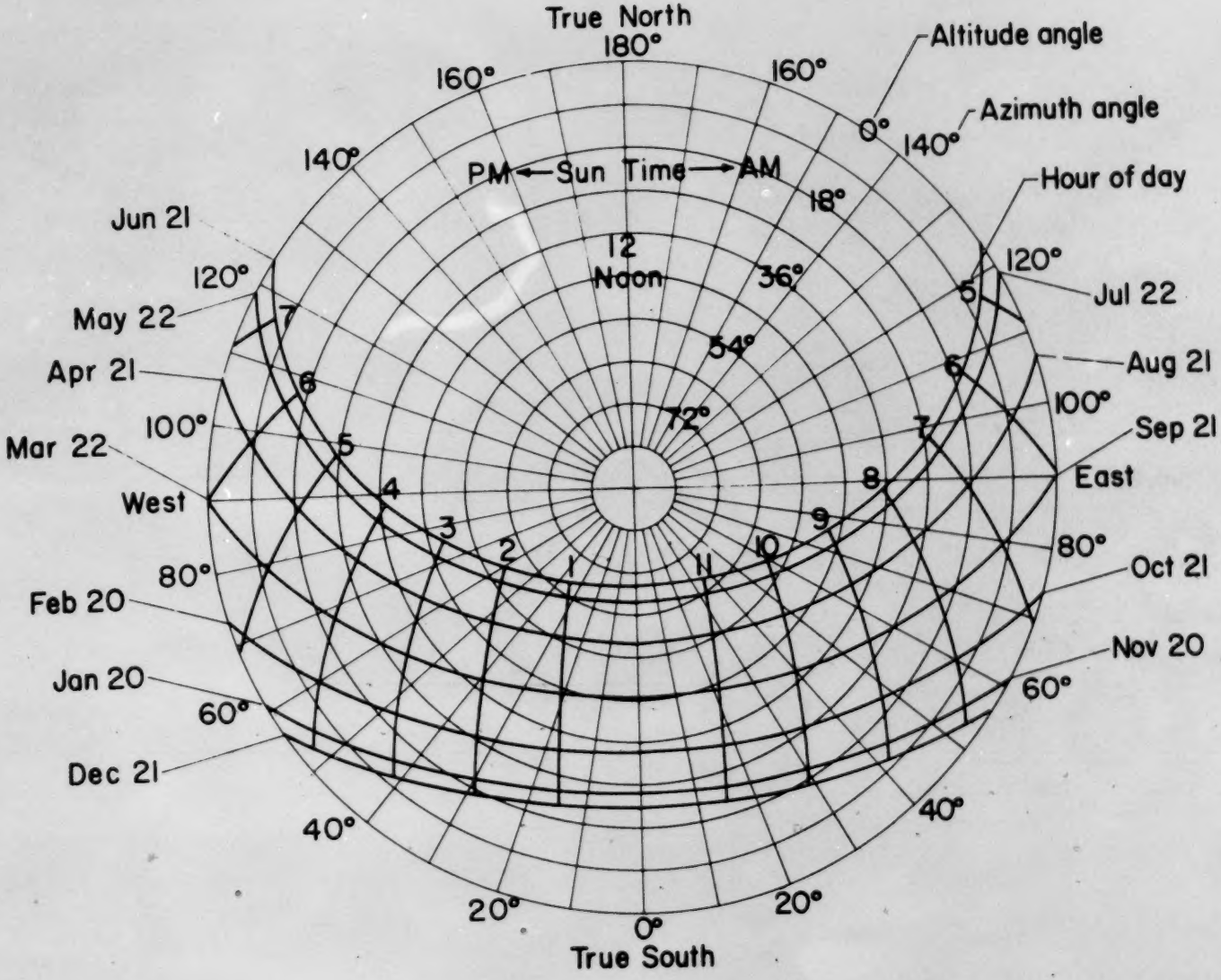


SUN CHART

40° N LATITUDE

113

113A

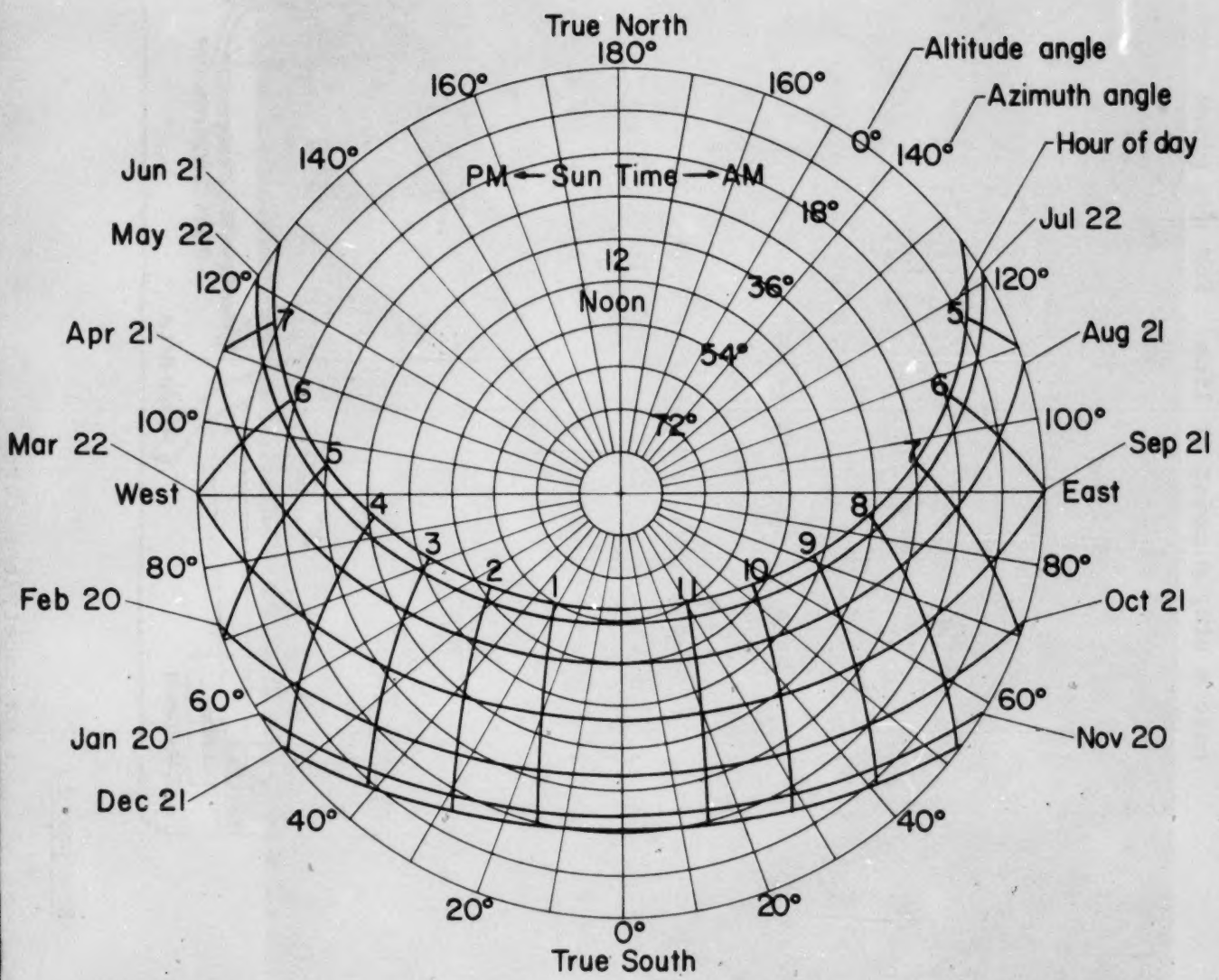


SUN CHART

44°N LATITUDE

114

114A

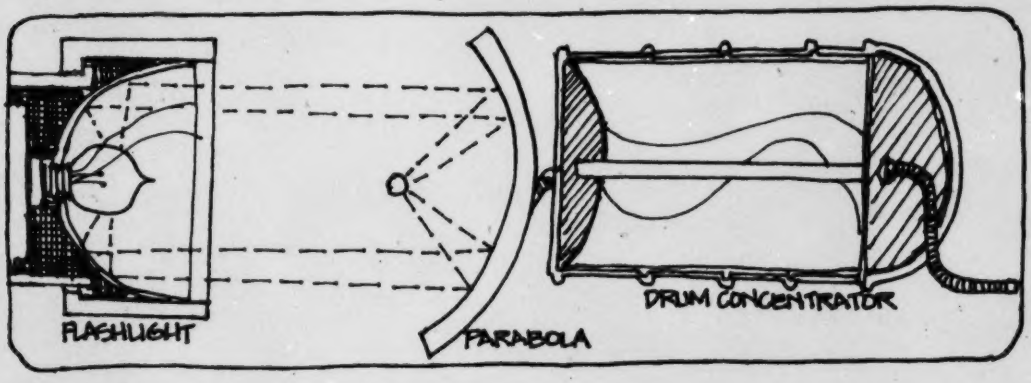


SUN CHART
48°N LATITUDE

PARABOLIC CONCENTRATOR

Introduction: Concentrating collectors focus the sun's rays onto a single point or line. For any given surface area, there is a total amount of available energy of about 250 BTU per square foot. This energy can be concentrated onto a line or a single point to achieve high temperatures. The amount of energy available to a solar concentrator and a flat plate collector of similar size is equal. However, the temperatures each unit can produce vary greatly.

There is one particular curve which focuses the sun's rays to one point or line. This curve is called a parabola. The curved shapes made by the cables of a suspension bridge are parabolas. The mirrored surface of a flashlight or an automobile headlight is also a parabolic curve.



Equipment:

1 oxy-acetylene torch

20" string for each team or group of students

red and black magic markers

framing squares (1 for each team or group of students)

1 5-gallon water pail for each team or group of students

Materials:

grocery bags (1 for each team or group of students)

½ sheet 1/4" plywood (1 per concentrator)

1 4'x8' sheet of Thermoply insulative sheathing (1 per concentrator)

1 55-gallon drum (1 for each two teams of students)

15 "L" brackets from scrap metal per concentrator

30 3/8" sheet metal screws per concentrator

5' 3/4" O.D. water pipe per concentrator

10' flexible hosing per concentrator

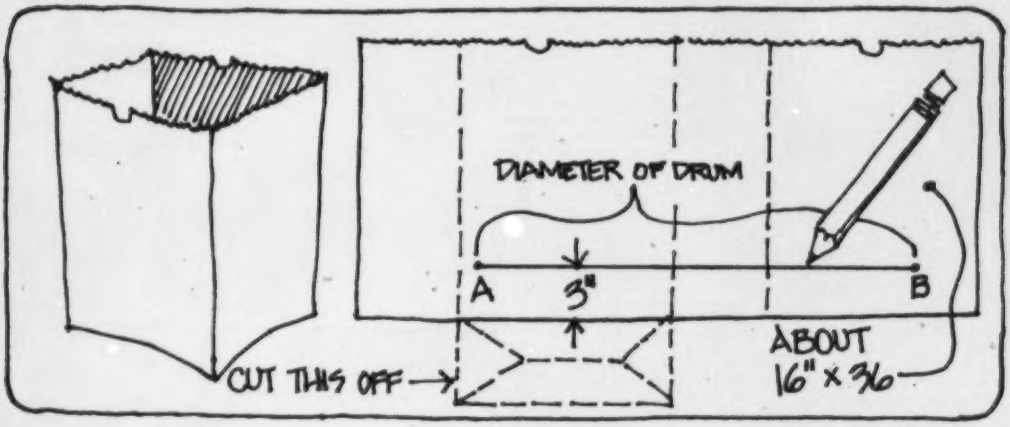
2 clamps per concentrator

Procedure:

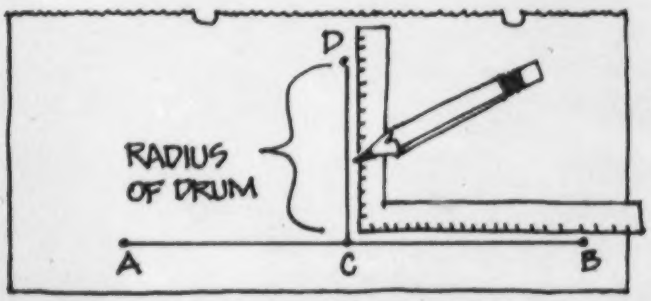
1. Measure and record the diameter and the radius (radius = diameter ÷ 2) of the drum.
2. With the torch, cut the drum in half lengthwise. (Caution: be sure the barrel of the torch is clean. Oxygen from the torch can cause severe fires or explosions if it comes in contact with certain chemicals.) The end pieces of the trough you have formed are semi-circles. It is not sufficient to line the inside of the drum with a mirrored surface at this time. Only the

parabolic curve has the property of reflecting incoming light onto one line or point. A circular curved surface will not do. The parabolic template is required to give the mirrored surface the proper optical properties.

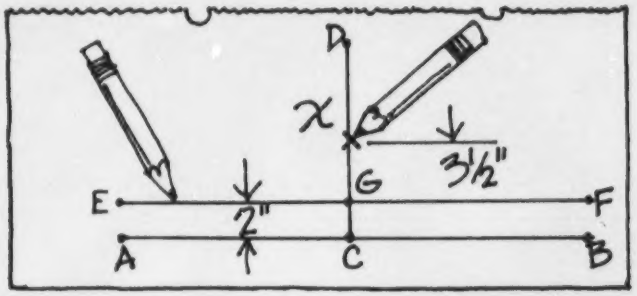
3. Cut along one edge of the bag to make one large sheet of brown paper. Place the paper on a flat surface and draw a line 3" from the bottom edge of the paper. Make the length of the line equal to the diameter of the section of the drum. Mark this line AB.



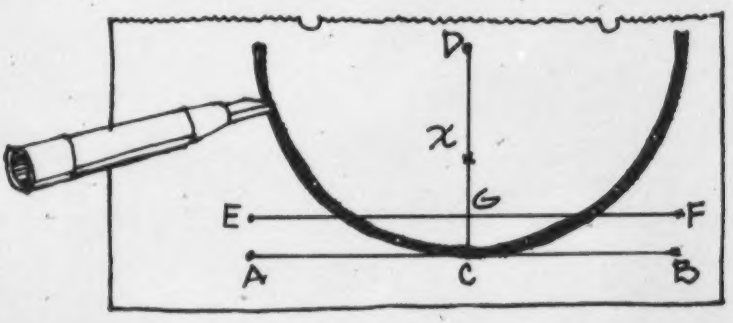
4. Find the mid-point of the line AB and mark it C. Use the framing square to draw a line perpendicular to AB at C. This line CD should be as long as the radius of the section of the drum.



5. Draw a second line EF 2" above and parallel to AB. This line should be the same length as AB. Mark the point where it crosses DC as G.
6. Place an X exactly 3½" above point G on line DC. This point X will become the focus for the parabolic form.

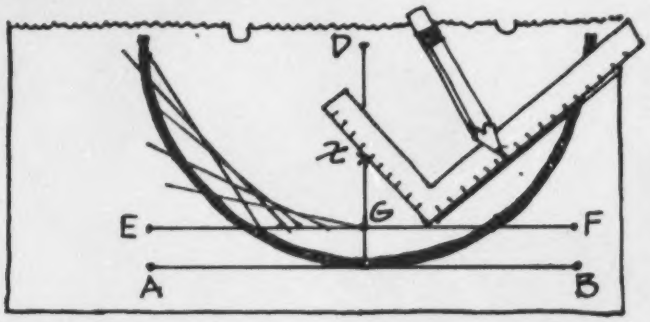


7. Make a compass by tying the string to the red magic marker. Place the loose end of the string at point D, and scribe a half-circle whose radius equals the radius of the original drum. We know that this half-circle will touch the line AB at C because DC was drawn equal to the radius of the original drum.



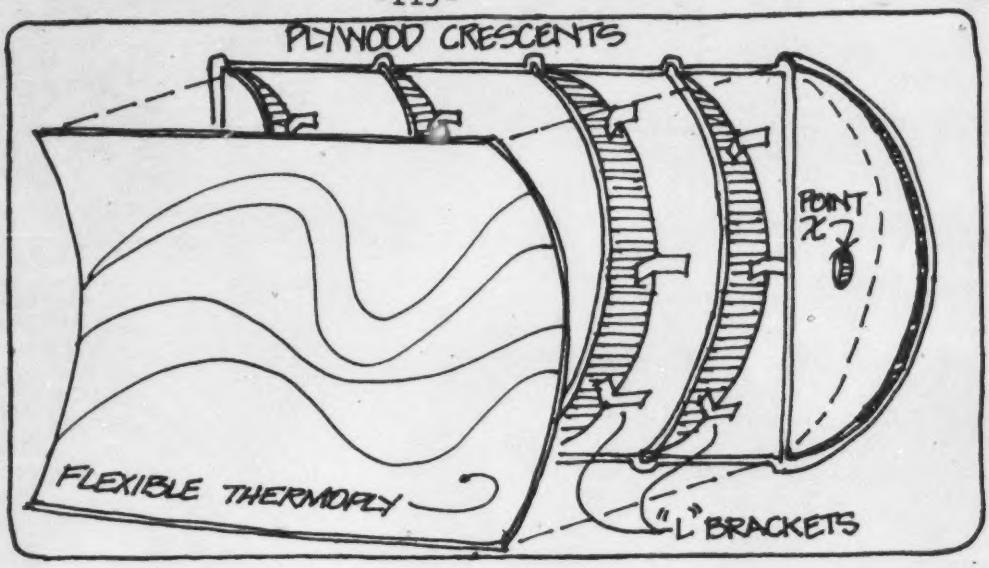
8. Place the framing square so that the heel just touches the line EF and the shorter arm of the

square passes through point X. Draw a line along the body of the framing square.



Repeat this procedure, moving the heel of the framing square in 1/4" intervals from point G to 3/4 of the way to F. The lines you have drawn will rough out the proper parabolic shape.

9. Repeat this process for the left side of the line (EG).
10. Blacken in the skinny crescent moon parabola you have made with the magic marker. This form will be used as a template for the section of the drum.
11. Cut out five of these parabolic templates from the piece of 1/4" plywood.
12. From sheet metal scraps, fabricate 15 "L" brackets with 1" sides. (These brackets may also be purchased, if you prefer.)
13. Attach the parabolic templates to the drum with the sheet metal screws. (See drawing on the next page.)



14. Place this flexible Thermoply insulative sheathing on top of the parabolic templates. In order to make the Thermoply conform more exactly to the parabolic templates, wire can be strung through the Thermoply to the back of the drum section in several places.
15. Attach the original brown paper drawing to the outside end pieces of the drum to determine where the X on the original template should be placed on the drum. The imaginary line connecting these two end points is the focal line of the concentrator.
16. Drill a hole through each end portion of the drum section at X.
17. Insert the 5' length of 3/4" O.D. water pipe into the holes. Hook up the clamps and hoses to the 5-gallon pail. This 5-gallon water reservoir becomes your heat storage.
18. Conduct experiments to measure temperatures of water entering and exiting from the collector.

Questions:

1. What happens to the shape of the curve when you move the focal point X farther away from the line EF?
2. What are the advantages or disadvantages of having the focal line farther away from the lining of the collector?
3. What would be the effect of using a #10 tin can instead of a 55-gallon drum? Could the same procedure be used? Would the smaller concentrator be able to achieve temperatures equal to those of the drum collector?
4. What can be done to insulate the collector line from the loss of large quantities of heat?
5. Because concentrating collectors require direct radiation, it is necessary for them to track the sun. Can you suggest a simple, inexpensive way to solve this problem on the collector you have just made?

WINDOW COLLECTOR

Introduction: This simple and effective solar window collector can be constructed within a very short period of time at a very low cost. It can be utilized for small load heat production by a room containing an unshaded southerly window. It functions on the principle of natural convection, or thermosyphoning: the simple falling of cold air and rising of warm air. In this case, cold room air travels into the lower duct on the collector, falls to the bottom of the unit, is warmed by the black absorber plate and rises back into the room via the upper "hot air" duct, thus creating a "syphoning" effect.

Objective: To construct a passive thermosyphoning solar window collector.

Materials:

Quantity	Material	Cost per Unit	Total
2	3/4" x 4' x 8' CDX plywood	$ 19.46	$ 38.92
1 pc.	1/8" x 24¼" x 64 3/4" glass	24.00	24.00
5 lbs.	8d common nails	.42/lb.	2.10
1 roll	duct tape	4.95	4.95
1 can	flat black spray paint	3.29	3.29
1 pc.	2" x 4" x 6'	.79	.79
1 qt.	exterior paint	4.30	4.30

Equipment:

table or skill saw

hammer

silicone caulking

Procedure:

1. Cut out all the pieces of plywood according to the layout pattern. Label these parts as indicated.
2. Run a saw kerf along the longest side of pieces C, C, E, F, G, and J as shown in the illustration, approximately 3/8" x 1/8". This kerf will recess the glass during the glazing procedure.
3. Nail the sides C, E, and G to base section A, making sure that corners are flush throughout the construction process.
4. Secure base section B to section A, and side the collector with sections D and F. It is recommended that small plywood gussets be nailed over the mitered seams for increased support.
5. Nail K to the rear portion of the collector as illustrated.
6. Cut eight 2" x 2" x 4" blocks from the 2" x 4". These blocks are used to support the absorber plate above the bottom of the collector. Position these blocks as shown in the illustration. Then secure pieces H and I in their respective locations.

7. Fasten the top of the collector J into place.
8. Spray paint the absorber plate and any pieces attached to it that are visible through the glazing with flat black rustoleum spray paint #412, or its equivalent.
9. Install the 24⅛" x 64 3/4" pane of glass on the collector, being certain that the glass is flush with the top edge of the collector sides. It is recommended that you use silicone caulking when doing this step to ensure a good seal.
10. Apply duct tape neatly along the edges where the glass is recessed.
11. Paint the entire exterior of your collector the desired color. Allow the collector to dry before installation.

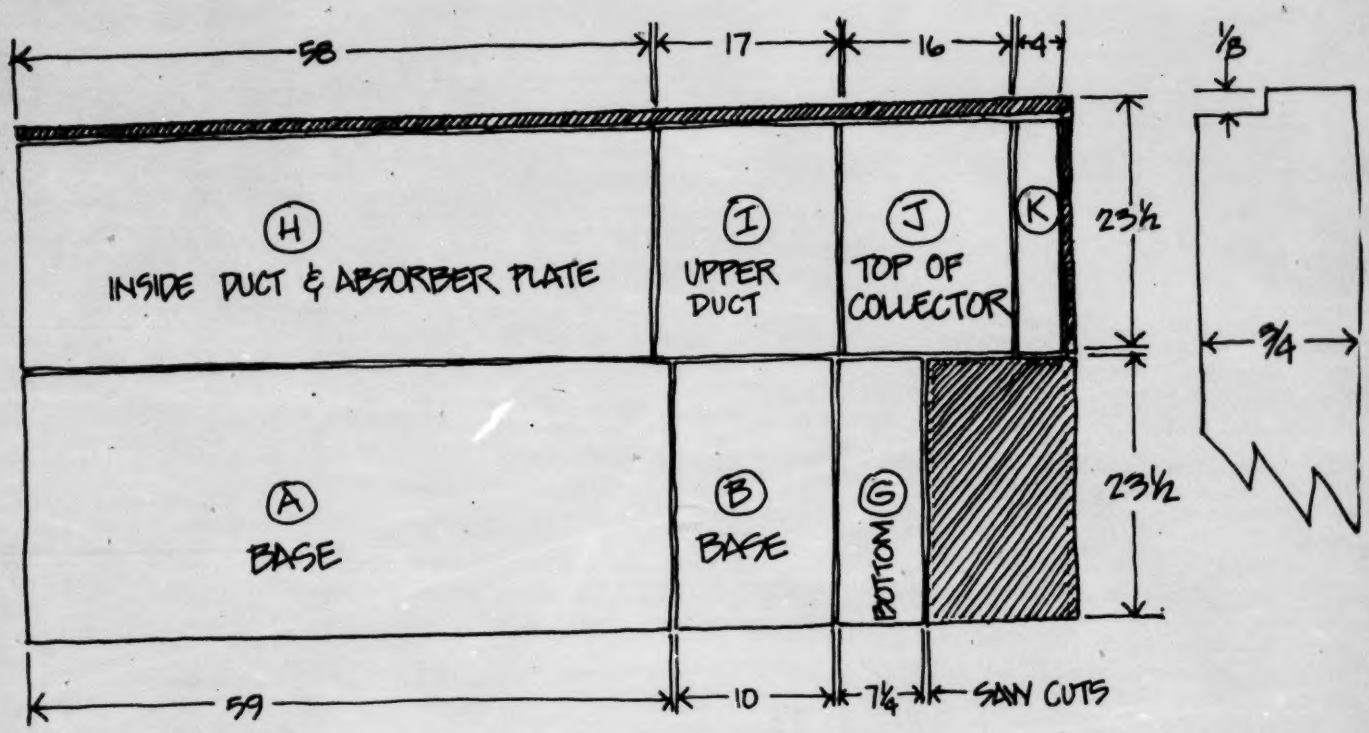
Installation:

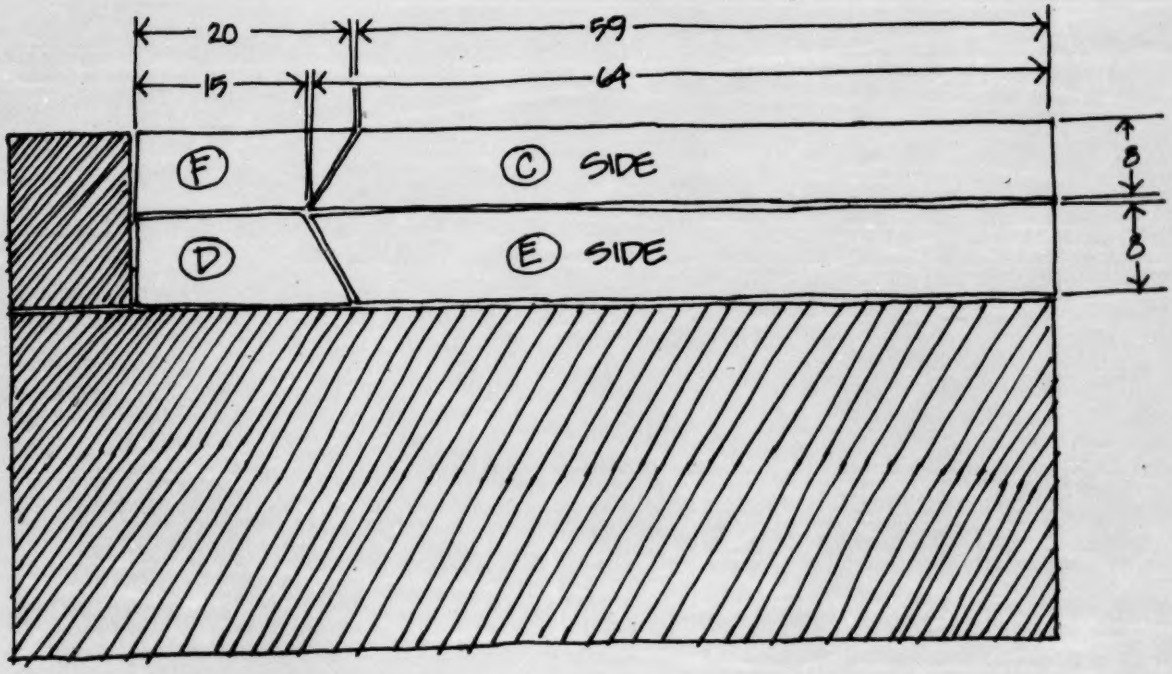
1. You must start by first determining which window in your house has a good southerly exposure to allow for the maximum amount of heating output provided by this unit.
2. Once a window has been chosen, it is simply a matter of making certain that proper insulation and weather stripping are installed to prevent heat loss.

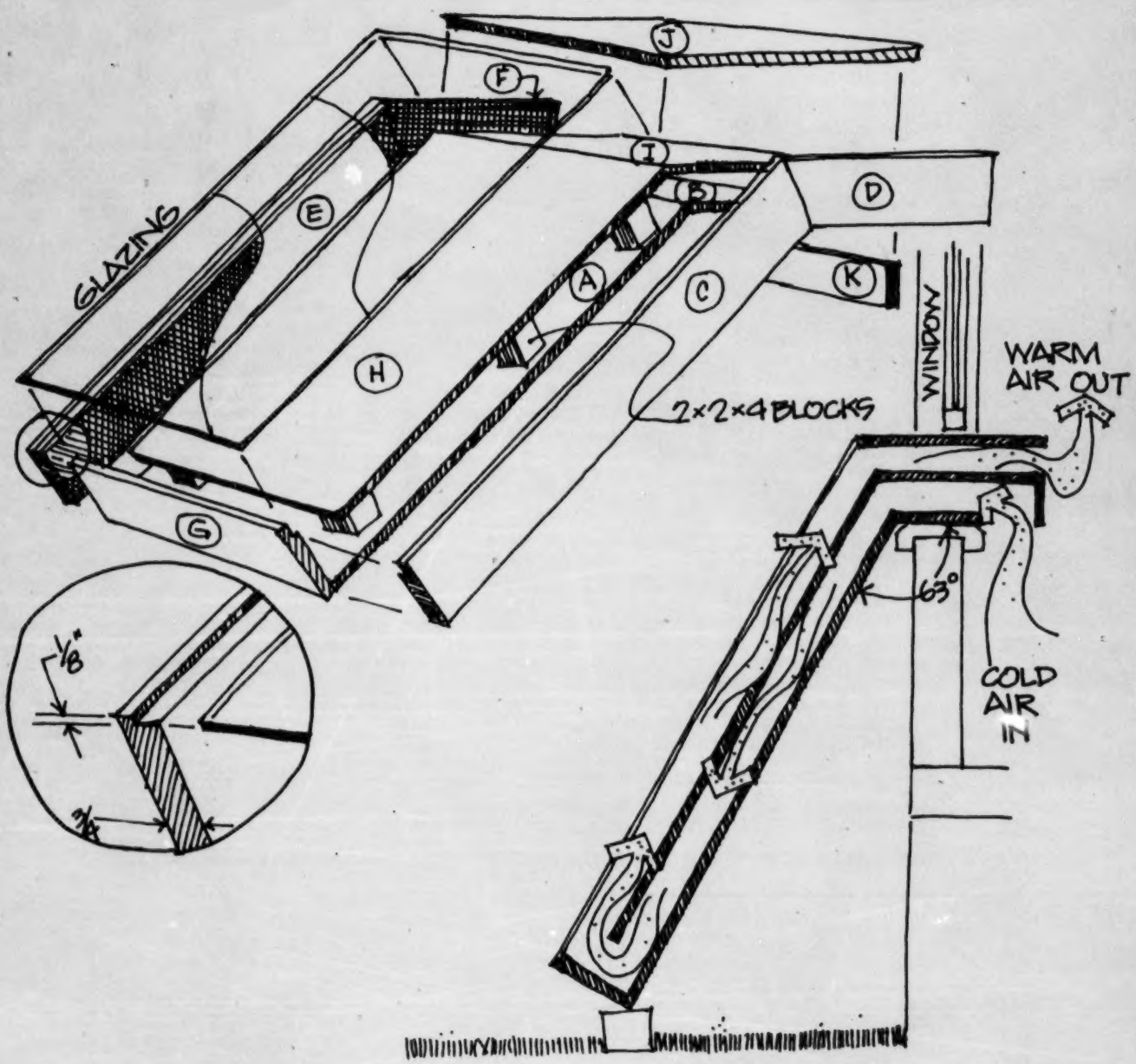
Use: This solar window collector has an advantage over many solar systems which are produced and marketed today. It is, in fact, a passive solar system; there are no blowers or pumps utilized in moving the air throughout the room. Once you've paid off the cost of construction and installation, the unit will provide inflation-free energy!

Questions:

1. What is the most efficient way of insulating around the window opening and the window collector?
2. How can you guard against reverse thermosyphoning at night?
3. What materials can be affixed to the absorber plate to make it more thermally efficient?
4. How many BTU can you hope to capture from this unit over the course of a 275-day heating season?


58
17
16
4
1/8
H
INSIDE DUCT & ABSORBER PLATE
I
UPPER DUCT
J
TOP OF COLLECTOR
K
23½
3/4
A
BASE
B
BASE
G
BOTTOM
23½
59
10
7¼
SAW CUTS


20
59
15
64
F
C SIDE
8
D
E SIDE
8


J
F
I
B
D
E
GLAZING
A
C
K
H
WINDOW
WARM AIR OUT
2×2×4 BLOCKS
G
63°
COLD AIR IN
1/8"
3/4"

SOLAR POD

Introduction: The cost of a solar system can decrease dramatically if planned as an integral part of a new structure. If the solar system uses conventional framing and materials, then it can become a part of the building itself. At the Maine Audubon Society's building, the solar air collector also serves as a southern roof. On new houses solar hot water collectors can be built to fit in between roof rafters. Spaces between joists can serve as air ducts. On-site construction of solar systems using conventional materials can be a very cost effective way to work.

The solar pod is built to serve two main purposes: 1) it familiarizes students with conventional framing details and materials, and 2) it provides students with a test device which can be used in a wide range of solar experiments. Collector glazings, thermal mass, insulation types, and absorber surfaces can all be tested.

Objective: to construct a solar house section -- or "solar pod" -- for use in the testing of a variety of component variables.

Equipment:

skill and hand saws
hammer
tape measure
drill and bits
1/8" countersink

Materials:

Quantity	Material	Price per Unit	Total
1	2" x 12" x 6'	$	$ 5.60
1	2" x 6" x 16"		5.12
7	2" x 4" x 12'		17.64
2	½" x 4' x 8' CDX plywood	12.46	24.92
2	½" x 4' x 8' sheetrock	4.20	8.40
60 sq.ft.	3½" fiberglass insulation	13.00	13.00
60 sq.ft.	4 mil polyurethane plastic	4.52	4.52
1	3/4" x 10" x 6' #2 or #3 pine		3.12
2	3/4" x 8" x 10' #2 or #3 pine		13.00
2	3/4" x 6" x 8' #2 or #3 pine		7.36
60 bd.ft. (120 lineal)	3/4" x 6" x 10' #3 or #4 pine T&G		50.40
5 lbs.	16d common nails	.42	2.10
5 lbs.	8d common nails	.42	2.10
3 lbs.	sheetrock nails	.84	2.52
1 gal	joint compound	3.70	3.70
1 pc.	approx. 2' x 4' glass (or other glazing)	13.79	13.79
1 tube	PL 200 siliconized latex caulking		1.25
1 quart	paint or stain for exterior finish		3.00

Procedure: Most all of the pertinent construction information can be found on the attached diagrams.

1. Construct the 2 x 6 deck measuring 32 3/4" square outside dimension (O.D.) and sheathe it with a piece of ½" CDX plywood.

2. Nail down the sole plate to which the studded walls will be attached.
3. All cuts at the top of the studded walls are made at a 60° angle which is the best for our purposes. Measure the stud lengths from the diagrams provided, keeping in mind the scale of 3/4" to one foot. The easiest method of cutting the studs is to make the 60° cut first, then measure from the longest point, making the 90° cross cut last.
4. Secure the studs to the sole plate and brace them with pieces of scrap materials.
5. The cutting of the front of the back top plate will probably be the most difficult and confusing part of the project. It consists of 60° cuts on each edge and should be made from one piece, 2" x 12" x 6'. Later, cut these pieces to the correct length according to the diagram.
6. Secure the top plates in position.
7. Sheathe the entire solar pod with the remaining ½" CDX plywood, with the exception of a 2" space allowed around the base of the project.
8. Side the solar pod with the #3 or #4 tongue-and-groove pine siding or substitute this for cedar clapboards (or equivalent), again allowing a 2" space around the base.

9. Insulate the interior, using the 3½" fiberglass insulation, followed by the installation of the 4 mil polyurethane vapor barrier.
10. Sheath the interior walls with ½" sheetrock, countersinking the heads of all nails.
11. Compound the joints of the sheetrock, taping seams where necessary.
12. Construct the glazing panel as shown in the diagram, caulking wherever necessary to prevent leakage. Do not attach the glazing panel as it has been designed to be interchangeable.
13. Seal or paint both the exterior and interior. Basic construction of the solar pod is now complete.

Use:

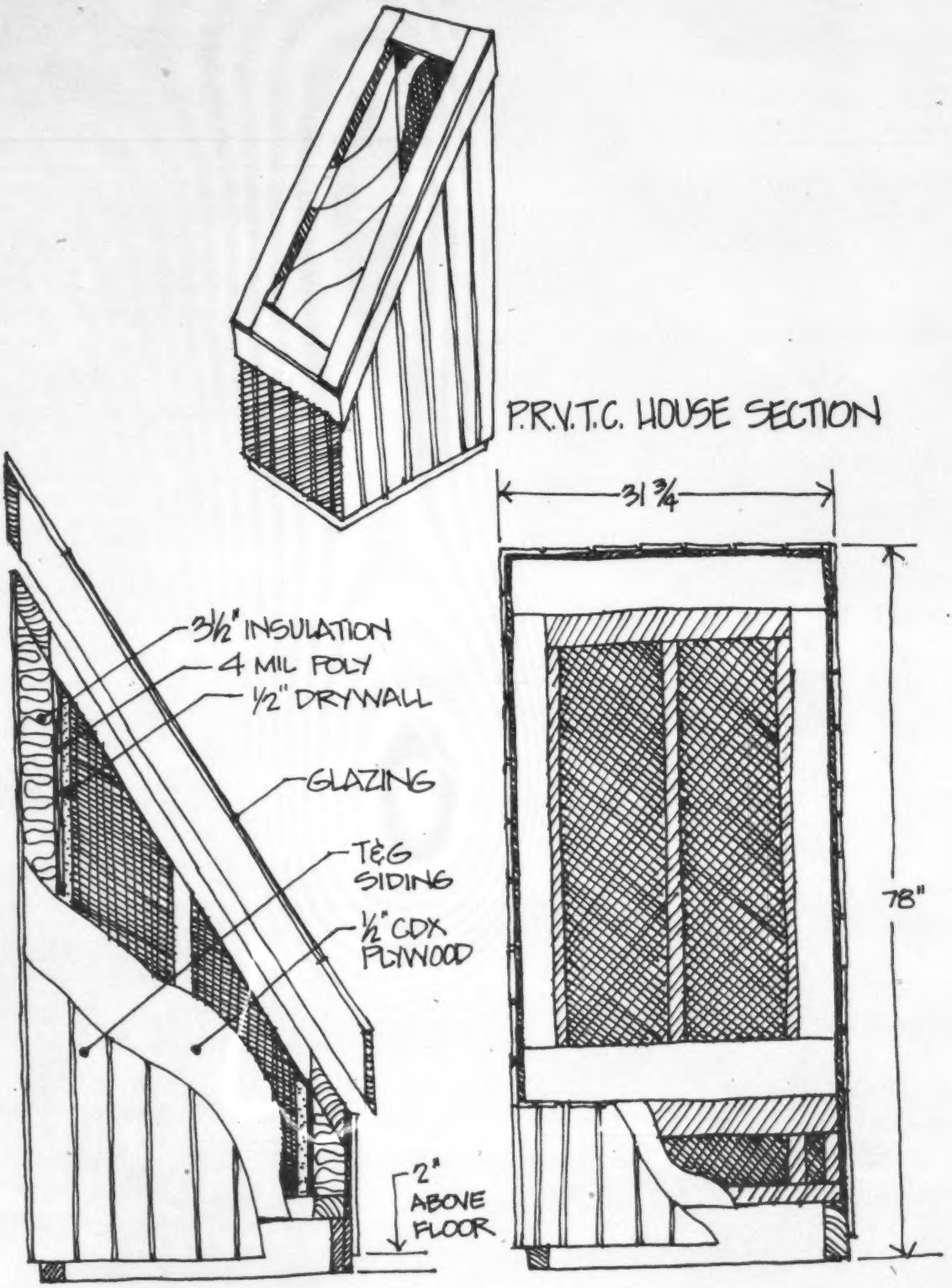
1. Place the solar pod in a location which receives much direct sunlight. Orient the solar pod with consideration given to wind direction, possible shading during the day and access to electricity if certain types of electronic temperature recording devices are to be used.
2. Place an electronic temperature recorder or a spring-powered plotting thermometer inside the solar pod. A max-min thermometer could also be used.
3. Collect the data over the course of several days. Compare these results with the solar weather data tabulated for the same period. What conclusions can you draw?

4. Vary the experiment by inserting a clear, gallon milk bottle filled with water. Graph the temperature swings over a similar period of time. A good way to make comparisons is to build two or three identical solar pods. Test them side by side to see if they perform equally first. If so, then begin changing the experimental variables, like adding filled milk bottles.
5. Record temperature swings after the water storage bottles have been painted flat black.
6. Replace the water bottles with an equal volume of washed river rocks 3/4" x 1½" in diameter. Record temperature swings.
7. Paint the rocks flat black. Record temperature swings. Compare these results with those collected while using the unpainted rocks.
8. Change the color of the inside surfaces, e.g. line them with aluminum foil, paint them white, flat black, green. Try a number of options. Record results.
9. Because the glazing panel is easily removed, a variety of glazing options are available. Assemble a double-glazed glass top section. Repeat the above experiments. Record temperature swings.
10. Obtain free samples, if possible, of a number of commercially available glazing materials, e.g. Kalwall, Tedlar, Mylar, or other synthetic glazings.

Call the toll-free solar information number (1-800-523-2929) for a listing of glazing manufacturers. Write to obtain free samples for your projects.

Questions:

1. What general conclusions can you reach about the following choices: a) single versus double-glazing; b) painted versus unpainted water bottles; c) painted versus unpainted rocks; d) rock thermal mass versus water for storage; e) glass covering versus synthetics; f) light interior versus dark interior. List other experimental choices. Write down results.
2. How could you frame out the solar pod so that the final unit would weigh less, but still have the same insulating properties?
3. What would be the effect of using a steeper angle, say 80°?


P.R.V.T.C. HOUSE SECTION
31 3/4
78"
3½" INSULATION
4 MIL POLY
½" DRYWALL
GLAZING
T&G SIDING
½" CDX PLYWOOD
2" ABOVE FLOOR

THERMAL SHUTTERS

Introduction: It has been estimated that heat loss through windows accounts for somewhere between 15%-20% of the total heat loss in a home. Window insulation devices can drastically reduce these losses. Many different designs have been produced, e.g. interior shutters, shades, removable panels, and drapes.

The following shutter design was provided by Cornerstones Energy Audits and the Homesworth Corporation of Brunswick, Maine. These particular shutters cost about $1.75 per square foot for materials. The R-value is more than 6. The Thermoply® acts as a vapor barrier, and the weather strip cuts down on infiltration losses.

Objective: To construct and install a thermal window shutter.

Materials:

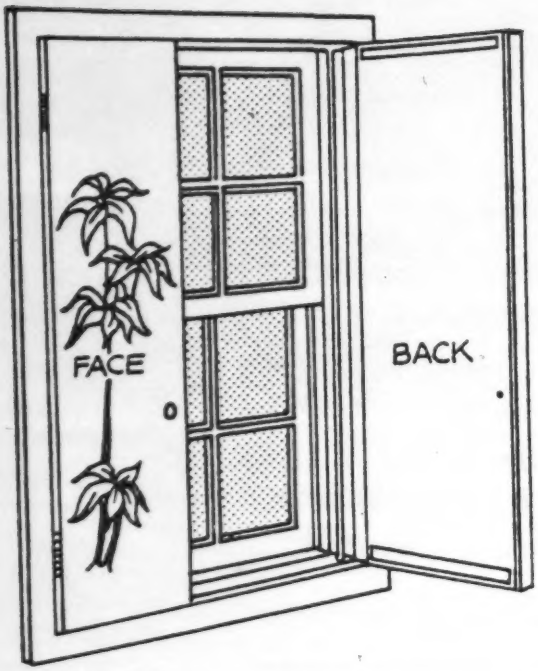
Quantity	Material	Price per Unit	Total
2	4' x 8' sheet of Thermoply® (one side white, one silver)	$6.50	$ 13.00
40 lin. ft.	1½" x 3/4" pine strips		3.20
4	3-hole hinges w/ screws	.40	1.60
2	cabinet knobs w/ screws	.20	.40
35 lin ft.	weather stripping		.35

Equipment:

staple gun
hand saw
utility knife
scissors
pencil
measuring tape
screw driver
Elmer's glue

Procedure:

1. Measure the opening of the window to be fitted with the thermal shutters. Write down both the inside width and height. Measure the width at both the top and bottom of the window. These window width measurements should be within 1/8" of each other.
2. Take the width and height measurements of the inside of the window casing and subtract 3/8" from each. Divide this new width dimension (W - 3/8") by 2. Record this data. This new width dimension will equal the width of an individual shutter piece. Remember, there are two of them for each window.

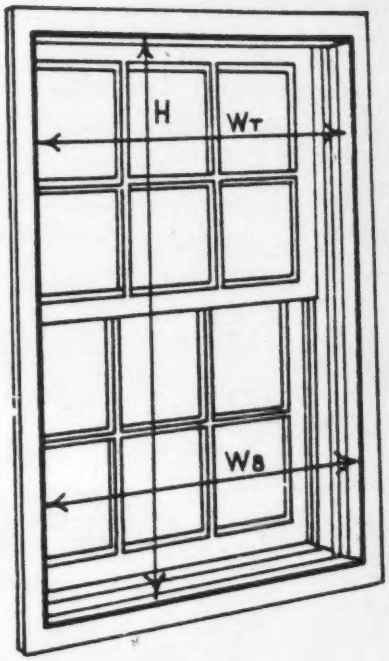


OPEN DURING DAY, CLOSED AT NIGHT.

MEASURE WINDOW HEIGHT, TOP WIDTH (W_T), AND BOTTOM WIDTH (W_B). SOME WINDOW WIDTHS AREN'T TRUE.

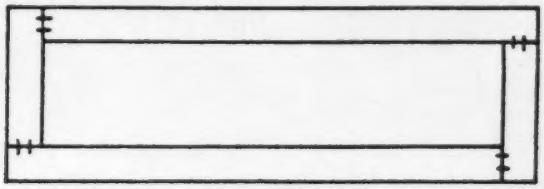
FOR PANEL DIMENSIONS, SUBTRACT 3/8" FROM H, W_T, AND W_B.

ONE HALF W_T AND W_B BY H IS THE DIMENSION OF EACH PANEL OF THE WINDOW PAIR.



3. Each shutter will require two pieces of Thermoply®, one on each side of the wood frames. Use the adjusted width and height measurements to mark off the pieces to be cut from the 4' x 8' sheets of Thermoply®. Make these markings on the white side of the Thermoply®.
4. Use the utility knife to cut the panels. Place the cardboard underneath the Thermoply® to avoid damaging underlying surfaces. Kneel on the Thermoply® sheets while cutting them. Cut carefully towards yourself for best blade control. Score lightly on the first cut. Increase pressure on next cuts until you cut all the way through. Check for comfortable fit in window opening before cutting the second panel.
5. If this panel fits well, cut out a second piece identical to the first one.

6. Measure the dimention of these two panels. Subtract ¼" from both the width and the height. Cut out two more panels of the new, smaller dimension. With the use of the 4' x 8' sheets of Thermoply®, you will have to piece together the 4th piece.
7. Cut the pine strips so that they form a wooden frame for the Thermoply®. Use the exact dimensions of the larger cut pieces of Thermoply® as a template for the wood pieces.



CUT 1×2 PINE STRAPPING TO FORM FRAME H, WT, AND WB. STAPLE TWICE PER JOINT ON BOTH SIDES.

8. Run a continuous glue bead around the face panel. Glue the frame to the panel.
9. Staple face edges to glued frame.
10. The appearance of the shutters will be improved if the shutter is covered with cloth. Select a fabric that complements the room interior. Cut a piece of fabric that has 4" extra on both the width and height to go around frame. Staple the extra cloth to the top portion of the wooden frame.

11. Center and then glue the smaller Thermoply® panels over the exposed wood frame.
12. Complete the above steps (7-11) for the remaining shutter half.
13. Place the two completed shutter panels back to back with fabric covered faces outside. Make marks on both pieces about 1/8 of the shutter length in from either end. Place the hinges at the pencil lines with the hinge pins toward the fabric side, and the other hinge edge along the edge of the panel. Do not set the hinges into the wood. Start the hinge screws by first punching the marked locations about 1/8" deep with a nail or other sharp object. Finally, turn the screws in until flush with the hinge face.
14. Cut and staple lengths of brown felt weather-stripping to the hinged edges of panels, except where the hinges occur. The white weatherstrip can be applied and stapled onto the panels themselves or onto the sash.

Use:

1. Install the shutters in the window frame. Use scrap pieces of the 1/8" Thermoply® to shim up the shutters. The finished pair of shutters should be placed with hinges closed within the

window frame. Moderate force may be required to force the shutter into place.

2. Once properly aligned, screw the hinges to the window stop. When shutters are closed together, they should "pop" into place and remain closed. If they don't, add a weatherstrip to one of the mating edges.
3. Add cabinet knobs. Mark correct locations and then punch these spots with a nail. Do not use a drill as the bit may rip the fabric.

Questions:

1. Why do windows require night insulation?
2. How does the installation of these shutters reduc heat loss in two ways?
3. What design changes can you suggest to improve the appearance of the shutters?